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# RESPIRATION.

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(*From the Cyclopædia of Anatomy and Physiology.*)

RESPIRATION (Germ. *Athmung*).—Before the nutritious juices of organized bodies can be properly elaborated and rendered fit for maintaining the vitality of the tissues through which they move, it is indispensable that certain chemical changes take place between them and the atmospheric air. All organized bodies, therefore, vegetable as well as animal, require a supply of atmospheric air for the continuance of life, and the amount of this is proportionate to the number and energy of their vital actions. These chemical changes between the nutritious juices of organized bodies and the atmospheric air constitute the important function of Respiration.

In studying the chemical actions that occur in respiration in different organized bodies, it is necessary to keep in mind the constitution of the atmospheric air, both in its free state and when dissolved in water. The atmospheric air, in its free state, is, as is well known, chiefly composed of nitrogen and oxygen, in the proportion of about 21 parts of oxygen to 79 of nitrogen by volume; or by weight, in the proportion of 23·1 of oxygen to 76·9 of nitrogen. Dumas and Boussingault, in their accurate experiments *, found the average proportion of these gases to be, by volume, 20·81 of oxygen, and 79·19 of nitrogen †; or by weight, 23·01 of oxygen, and 76·99 of nitrogen. The quantity of carbonic acid gas in the atmospheric air is very much smaller than that of the oxygen and nitrogen. Theod. De Saussure ‡, in his experiments,

* Annales de Chimie et de Physique, troisième série, tom. iii. p. 257. 1841.

† Or, what would be sufficiently accurate, 20·8 oxygen and 79·2 nitrogen.

‡ Annales de Chimie et de Physique, tom. xxxviii. p. 411. 1828.

found the maximum quantity of carbonic acid gas in 10,000 parts of atmospheric air to be 6·2, the minimum 3·7, and the average 4·9 or nearly 1 part, by volume, of carbonic acid gas in 2000 parts of atmospheric air. Results similar to those procured by Saussure, who experimented at Geneva, have been obtained by Boussingault* and Thenard† at Paris, Brunner‡ at Berne, and Verver§ at Groningen in Holland, so that we have the strongest grounds for believing in their general accuracy. The variable quantity of watery vapour that exists in the atmosphere must also be taken into account in examining the function of respiration. A quantity of ammonia, so small however that its usual proportion cannot be ascertained, is constantly present in the atmospheric air, which, when it descends to the earth dissolved in water, serves, according to Liebig, an important purpose in the nutrition of vegetables. There are, besides the above substances, numerous others in the gaseous form, exhaled from the surface of the earth, too minute to be detected by analysis, but sometimes recognised by their effects upon the living organism. No doubt the miasmata and effluvia, which can inflict such disastrous evils on the human race, are diffused through the atmospheric air.

Though the proportions of the three gases, viz. nitrogen, oxygen, and carbonic acid, usually regarded as forming the constituent parts of our atmosphere, are not quite uniform at all times and in all places, chiefly from local disturbing causes, yet these differences are to a small extent, when its free circulation is permitted. Dalton ‖ maintained, that in elevated regions the proportion of oxygen to azote is somewhat less than at the surface of the earth; but this is not confirmed by the more recent experiments of Dumas, Boussingault, and Brunner. In the experiments of Lewy ¶ and Morren **, the composition of the air near the surface of the sea differed in its amount of oxygen from that over the land. Saussure detected a somewhat smaller quantity of carbonic acid gas in the air during the day than during the night *, and a larger quantity in the air of the town of Geneva than in that taken in the country three-fourths of a league distant, in the proportion of 100 to 92; and Boussingault and Lewy, in their later experiments, observed a similar difference between the air taken from the densest parts of Paris and that of the country.† Lewy detected a considerable increase of carbonic acid gas, no doubt of volcanic origin, in the air of Guadaloupe, but without any diminution in the usual relative proportions of the oxygen and nitrogen.‡ As a portion of the oxygen of the atmospheric air is combined with carbon to form carbonic acid gas in the respiration of animals, in ordinary combustion, and in numerous other chemical processes going on at the earth's surface, it is obvious that when individuals of the human species are surrounded by a limited quantity of air which is not renewed so rapidly as it is vitiated by respiration, the proportion of oxygen gas will be diminished and the carbonic acid increased, and this the more rapidly if any other process of deoxidation of the confined air be at the same time in operation. Dalton analyzed the air of a room where 50 candles had been kept burning and 500 people had been collected for two hours, and found that it contained 1 per cent. of carbonic acid gas.§ Leblanc made a number of analyses of the air taken from the rooms of some of the public buildings in Paris. ‖ He collected some of the air of one of the wards of La Pitié, the area of which was 70,632 cubic feet, containing 54 patients, after it had been shut during a whole night, and procured from it 3 parts of carbonic acid gas, by weight, in the 1000, or about 5 times as much carbonic acid as is usually present in the atmosphere.¶ The oxygen gas had suffered a corresponding diminution. In one of the sleeping apartments of the Salpetrière, the carbonic acid gas amounted to 6 parts, by weight, in the 1000 parts of the contained air, and in another sleeping apartment to 8 parts in the 1000.** In the Amphitheatre of Chemistry at the Sorbonne, the air collected at the end of the lecture furnished 10·6 of carbonic acid, by

* Annales de Chimie et de Physique, tom. x. p. 456. 1844.

† Referred to in opus supra citatum, tom. x. p. 463. 1844. Thenard's experiments were made prior to those of Saussure.

‡ Opus supra cit. tom. iii. p. 313. 1841.

§ Referred to in opus supra cit., tom. x. p. 462. 1844.

‖ London and Edinburgh Philosophical Magazine and Journal of Science, vol. xii. p. 406. 1838.

¶ Annales de Chimie et de Physique, tom. viii. p. 425. 1843. Lewy found the quantity of oxygen in the air near the surface of the North Sea on an average 22·6 by weight in the 100 of air, while the air over the land contained 23 of oxygen in the 100.

** Annales de Chim. et de Phys., tom. xii. p. 5. 1844. Morren states that the air resting upon the surface of the sea, in calm weather, may contain from 23 to 24 parts, by volume, of oxygen instead of 20·8, the usual quantity; and this increased quantity of oxygen, under the circumstances mentioned, is connected, as we shall see immediately, with the action of the marine vegetation upon the atmospheric air. The experiments of Lewy and Morren are not contradictory; for in those of the former the air was taken from the surface of the deep sea at some distance from the shore, and in those of the latter the air analyzed had been resting for some time over pools of sea-water abounding in algæ, exposed to the sun's rays.

* Boussingault (opus cit. tom. x. pp. 464, 465) obtained similar results; but he admits that more extended observations are required on this point.

† Annales de Chim. et de Phys., tom. x. p. 470. 1844.

‡ Idem opus, tom. viii. p. 450. 1843.

§ London and Edinburgh Philos. Mag., vol. xii. pp. 405, 406. 1838.

‖ Annales de Chim. et de Phys., tom. v. p. 223. 1842.

¶ If the usual quantity of carbonic acid in the atmosphere be from 4 to 6 in the 10,000 parts by volume, that is equal to from 6 to 9 of carbonic acid gas by weight.

** Opus cit., p. 233.

weight, in the 1000. The air collected in the pit of the Opéra Comique a short time before the termination of the performance contained 2·3; while in another experiment the air from one of the boxes contained 1·3, by weight, of carbonic acid gas in the 1000. In one of the stables at the Ecole Militaire, the air collected after it had been kept closed for a night yielded 1·05 in the 100; and the air from another which was better ventilated yielded about 2 parts in the 1000, by weight.* If, according to the opinion of Leblanc and others, carbonic acid gas exerts a prejudicial effect upon the vital actions in the human species when it has accumulated to the extent of 1 per cent. in the air to be breathed, the above facts, to which many others might readily have been added, point out the importance of securing sufficient ventilation both in our private and public buildings.

As the gases held by water in solution supply the means of aquatic respiration to many animals and plants, a knowledge of the quantity and composition of these gases is also necessary for the full comprehension of the function of respiration. Humboldt and Gay Lussac state that the water of rivers, and distilled water well aired, hold in solution about $\frac{1}{27}$th of their volume of air composed of about 32 of oxygen and 68 of azote, by volume.† Morren ‡ concludes from his experiments that sea-water contains in solution between $\frac{1}{45}$th and $\frac{1}{50}$th of its volume of air, a quantity sensibly less than that obtained from fresh-water, which usually contains from $\frac{1}{30}$th to $\frac{1}{25}$th, or even $\frac{1}{20}$th of its volume.§ He found that the air obtained from fresh-water under ordinary circumstances, whether distilled and again perfectly aërated, or the limpid water of a moderately rapid stream, contains 32 parts of oxygen, and from 2 to 4 of carbonic acid, by volume, in the 100; while the air obtained from sea-water yielded 33 of oxygen and from 9 to 10 of carbonic acid in the 100. The relative proportion of the gases obtained both from fresh and sea-water varies considerably under certain conditions. In fresh-water ponds abounding in plants or green animalculæ, and in shallow parts of the sea, where numerous algæ flourish, the proportion of oxygen gas may be considerably increased during sunshine, especially if the water be at the same time still. Morren analyzed, in a bright day in July, the gas dissolved in the water of a fish-pond of a green colour, chiefly from the numerous animalculæ it contained, and found in that procured in the morning 25, at mid-day 48, and in the evening as much as 61 of oxygen in the 100 parts.* Similar changes, but to a less extent, were detected by Morren in the air of sea-water, and they are chiefly dependant upon the action of the algæ. In one experiment, performed on a fine sunny day, when the sea was at the same time calm, the air obtained from the water yielded 40 per cent. of oxygen in the early part of the day, and 53·6 in the evening. The total quantity of air obtained from both kinds of water varied at different times of the day; and its increase was chiefly dependant upon the addition of oxygen, the carbonic acid at the same time suffering a decrease, but not in the same proportion, while the nitrogen † seemed to suffer little change. This increase of oxygen will partly contribute to the supply required for the respiration of the numerous aquatic animals which usually frequent the localities where it is evolved, and be partly given off to the superincumbent air, and thus assist in maintaining the purity of the atmosphere.

Notwithstanding the large quantity of oxygen daily removed from the atmosphere by the respiration of animals and other causes, yet from the great extent of the atmosphere, and the rapid mixture of its different parts, a long period of time must necessarily elapse before it suffers any marked deterioration, even were there no compensating operation in the vegetable kingdom. The oxygen gas in the atmosphere is equal in weight to a column of 7·8 feet of water pressing upon every part of the earth's surface: and it has been stated that it would require 10,000 years, supposing the earth peopled with 1,000,000,000 of men to produce a perceptible effect upon the eudiometer of Volta, even though vegetable life was annihilated; and that to suppose *all the animals* on the surface of the earth could by

* According to the experiments of M. Lassaigne (Comptes Rendus, 13th Juillet, p. 108. 1846) the carbonic acid gas, formed by respiration in apartments where the ventilation is very imperfect, is not confined to the parts nearest the floor, but is diffused nearly in equal proportions through every portion of the mass of air in the apartments.

† Journal de Physique et de Chimie, par Delamitherie, tom. lx. p. 158. The percentage of oxygen from the air of water of the Seine was 31·9; of distilled water which had again absorbed air, 32·8; and of rain water, 31·0. (p. 159.)

‡ Annales de Chim. et de Phys., tom. xii. 1844.

§ M. Lewy (Comptes Rendus, 28th Sept. 1846) states that, in his experiments, one litre (61·027 cubic inches English) of Seine water yielded about 40 cubic centimetres (2·440 cubic inches) of air, and the same quantity of water from the ocean furnished only 20 cubic centimetres (1·220 cubic inches). The water of the ocean, in consequence of the salts it holds in solution, absorbs much less atmospheric air than fresh water.

* Opus cit. p. 9. Wöhler (Poggendorff's Annalen der Physik und Chemie, band lvii. S. 308. 1842) analyzed the gas exhaled from the greyish yellow mass, consisting in a great measure of living infusoria mixed with some confervæ, which collects in a salt spring at Rodenberg in Hesse, and found it to be composed of 51 per cent. of oxygen, and 49 of nitrogen.

† M. Lewy (Comptes Rendus, 28th Sept. 1846) has observed similar changes, but not to the same extent, in the relative proportions of oxygen and carbonic acid in the air of sea-water under the circumstances mentioned by Morren. According to the results of Lewy, the waters of the ocean contain a small quantity of sulphuretted hydrogen gas, apparently evolved from the bodies of certain molluscous animals, which may be imparted to the air resting upon the surface of the water; and Dumas, in his report upon Lewy's Memoir, throws out some remarks on the possibility of the sulphur contained in this gas serving an important purpose in the nutrition of plants.

their respiration deteriorate the air to the extent of removing in a century the 8000th part of the oxygen in the atmosphere, is to make a supposition very much beyond the truth.*

*Respiration of plants.* — The results of the chemical actions between the atmospheric air and the vegetable kingdom, are chiefly influenced by the presence or absence of light, and the condition of the plants at the time. When a plant is surrounded by the ordinary atmospheric air, and exposed to the sunshine, the green parts of the plant, and especially the leaves, decompose the carbonic acid contained in the atmosphere, seize upon the carbon, and liberate the oxygen; while the same plant in the dark, not only ceases to decompose carbonic acid, but actually exhales into the surrounding atmosphere a portion of this gas. A quantity of nitrogen gas is also given off by plants along with the oxygen.† Plants, therefore, during exposure to light, purify the air by removing carbonic acid and adding oxygen, while during the night they, like animals, deteriorate the air by exhaling carbonic acid gas. As, however, the quantity of oxygen gas liberated during the day from the decomposed carbonic acid is more than sufficient to counterbalance the quantity of carbonic acid formed during the night, plants on the whole must counteract, either entirely or in part, the accumulation in the atmosphere of the carbonic acid gas formed by the respiration of animals, and in various chemical processes going on at the earth's surface. Indeed, nearly the whole of the carbon which enters so largely into the formation of the vegetable tissues, appears to be obtained through the decomposition of the carbonic acid of the atmosphere.

The parts of a plant which are not of a green colour, such as the roots, &c., absorb oxygen from the atmosphere, and give out carbonic acid gas even in the sunshine; and this process seems essential to the vigorous growth of the plant. The flowers of a plant also absorb oxygen, and exhale carbonic acid, and the quantity of the latter gas evolved during inflorescence is considerable. The seeds of plants during germination also absorb oxygen and give out carbonic acid.‡ The Fungi evolve carbonic acid gas in large quantity from all parts of their structure, and at all periods of their growth, even when exposed to a bright sunshine, and these plants derive their supply of carbon from the soil in which they grow.* It is also maintained that a quantity of oxygen is absorbed by the surface of plants during spring and summer, to assist in the elaboration of their acids, resins, and volatile oils. We thus perceive that the chemical actions between the atmospheric air and plants are varied, and differ in some important respects from those that occur in animals. Attempts have been made to show that the respiratory function is essentially the same in these two great divisions of the organic kingdom; that the fixation of carbon and the liberation of the oxygen gas by the leaves, and other green parts of plants during their exposure to the rays of the sun, form a part of their digestive process; while the evolution of carbonic acid, which proceeds during the day as well as during the night, from seeds during germination, from the flowers, from the surfaces not coloured green, and also, it is asserted, partly from the leaves, is their true respiratory process.† According to others, if the actions of the juices upon the atmospheric air, by which they are changed from the crude to the fully elaborated sap, and rendered fit for the nutrition of the plant, constitute the function of respiration, then the green surfaces, and especially the leaves,

* Dumas' Essai de Statique Chimique des Etres Organisés, p. 18, 3rd edit. 1844; and Dumas and Boussingault in Annales de Chim. et de Phys., tom. iii. p. 288. 1841.

† Daubeny, in Philos. Transactions of London for 1836, p. 149; and Professor Draper, in London, Edinburgh, and Dublin Philosophical Magazine, vol. xxiii. p. 161. 1843. According to Draper, "when the leaves of plants under the influence of light decompose carbonic acid gas, they assimilate all the carbon, and a proportion of oxygen disappears, at the same time they emit a volume of nitrogen *equal to that of the oxygen consumed.*" The greater part of the nitrogen evolved comes, he believes, from the decomposition of some nitrogenized constituent of the leaf.

‡ The animalcula, especially those of a green colour, seem to exert the same effects upon the atmospheric air under the influence of light as the green parts of plants. Vide observations of Morren and Whöler, already referred to; and also Ehrenberg, in Poggendorff's Annalen, band lvii. S. 311.

* Marcet (Bibliothèque Universelle de Genève, (Sciences et Arts,) tom. lvii. p. 393. 1834; and Annales de Chim. et de Phys., tom. lviii. p. 407. 1835) ascertained that Fungi, when confined in a limited quantity of air for some time, disengage a larger quantity of carbonic acid gas than could have been formed by the combination of carbon with the oxygen which has disappeared from the air: that when confined in nitrogen gas, a small quantity of carbonic acid is evolved, and in some cases a small quantity of nitrogen is absorbed; and that when confined in oxygen gas a larger quantity of this gas is absorbed than what is sufficient to constitute the carbonic acid gas evolved, and that this is replaced, at least in part, by a quantity of azote disengaged from the plants. We thus perceive that if certain of the lower organized bodies, generally regarded as belonging to the animal kingdom, effect the same changes upon the atmospheric air by their respiration as the higher vegetables do, there are, on the other hand, certain of the lower organized plants that resemble in this respect the higher organized of the animal kingdom. Other cryptogamic plants having a green colour, such as the Ferns and Algæ, liberate oxygen gas when exposed to the sunshine. Vide Morren's Experiments on Algæ, already referred to; and those of Daubeny, upon Ferns and Algæ, in London Philos. Transact. vol. xlii. p. 166. 1836.

† Burnett, in the Journal of the Royal Institution of Great Britain, vol. i. p. 83. 1831. Mr. Burnett also maintains that the analogy further holds good "between the functions of respiration and digestion in animals and plants, for to both is carbonic acid deleterious when breathed, and to both is it invigorating to the digestive system when absorbed as food," p. 100. Professor Draper (London and Edin. Philos. Magazine, 1844) proceeds still farther, and asserts that the whole of the action of the leaves upon the atmospheric air constitutes a true digestive and not a respiratory function.

are the true respiratory organs of plants.* Besides, it has been alleged that the evolution of the carbonic acid gas from the leaves during the night is not attended by an absorption of oxygen, as in the respiration of animals; that it is a mechanical process, having no connexion with the nutrition of the plant; and that it depends upon the carbonic acid absorbed along with the water by the roots and leaves, escaping into the air along with the water evaporated during the periods when the plant, as in the absence of sunshine, is incapable of fixing the carbon.† As the respiratory process in animals forms a part of the great Nutritive Function, for preparing, elaborating, and assimilating the nutritious juices, and as the two functions performed respectively by the digestive and respiratory organs in the higher animals are not definitely separated in the vegetable kingdom, we can readily understand that the same structures in the vegetable kingdom which carry on the process of respiration, may also at the same time assist in the performance of other parts of the nutritive function.

In some of the lower organized plants every part of their surface is probably equally efficient in the performance of the function of respiration; while in the higher plants, though the whole of the external surface may still aid, the leaves are the chief organs of respiration. Botanists are not agreed as to what extent the spiral tubes, usually regarded as analogous to the tracheæ of insects, act as organs of respiration. These spiral vessels do not form continuous canals, and do not open upon the stomata, so that the air cannot enter them without having previously permeated a greater or less thickness of vegetable tissue covering them. Their share in the performance of the function of respiration cannot, probably, be great.

*Respiration in animals.* — The function of respiration varies greatly in activity, and in the external form and position of the apparatus by which it is effected, in the different divisions of the animal kingdom. In all animals, except some Infusoria, the nature of the chemical changes between the atmospheric air and the nutritious juices is pretty uniform, and essentially consists in the evolution of carbonic acid gas and the absorption of oxygen. Azote may be exhaled by, or absorbed at, the respiratory organs in small quantities; but these changes seem to be of secondary importance in the function of respiration, do not appear to be uniform in the same animals at different times, and occasionally cannot be detected. The evidence, however, preponderates in favour of the opinion that a small quantity of azote is exhaled at the respiratory organs.

The function of respiration in animals includes two distinct processes — the evolution of one gas from the nutritious juices, and the absorption of another; and while the former is an act of excretion necessary for the maintenance of the purity of the nutritious juices, the latter is an act of absorption necessary for their proper elaboration. These two acts are of equal importance in supporting the vitality of the organism, are so closely linked together, and are so reciprocally dependent for their continued action, that they have been regarded as belonging to the same function, though in a logical point of view they are parts of two distinct functions, viz. 1st, the absorption by the organism of new materials from the surrounding media for completing the elaboration of the nutritious juices; and, 2dly, the excretion from the organism of those substances which are of no further use, and would even prove prejudicial if retained. Many of the definitions given of the respiratory process are liable to strong objections in consequence of its compound character not having been kept strictly in view. These mutual actions between the nutritious juices and atmospheric air are purely chemico-physical, take place wherever the air and the fluids are brought into contact, and do not require the agency of vitality for their manifestation. When a urinary bladder has been filled with venous blood and placed in atmospheric air, the oxygen of the atmospheric air, and the free carbonic acid in the blood, mutually permeate the coats of the bladder, the oxygen gas being absorbed by the blood, and the carbonic acid escaping into the surrounding atmosphere. This interchange depends upon the strong tendency that different gases have to intermix or diffuse themselves through each other, and as this action in this particular case takes place through a permeable membrane, it may be regarded as a kind of endosmose and exosmose.

It necessarily follows, that wherever the nutritious juices of organized bodies are separated from the atmospheric air by tissues permeable by oxygen and carbonic acid gas, the function of respiration may be performed. The energy of this function will be regulated by the following conditions: — the greater or less thickness and permeability of the tissues interposed between the atmospheric air and the nutritious fluids; the quantities and constitution of these substances thus brought into action; the extent of surface over which they operate; and the rapidity with which fresh portions of both are brought into contact, in the place of those whose mutual actions have been completed. In the higher animals, where this function is performed in greatest perfection, the apparatus for effecting it is very complicated and extensive, and consists, 1st, of a special organ — the lungs, affording an immense extent of surface where the blood flows in innumerable minute streamlets only separated by very thin membranes from the atmospheric air; 2dly, of an assemblage of muscles, bones, and nerves, for efficiently renewing the air in the lungs; and, 3dly, of a series of vessels with a contractile propelling organ attached to them — the pulmonary arteries and veins and right side of the heart, — for rapidly

* Cours Elémentaire d'Histoire Naturelle. Botanique par M. A. de Jussieu, p. 177.

† Liebig's Organic Chemistry, translated by Playfair, p. 31. 1840. Hunt's Researches on Light, p. 194. 1844. Dumas' Essai de Statique Chimique des Etres Organisés, 3rd ed. p. 24. 1844.

changing the blood in the lungs, and bringing successive portions of it into contact with the atmospheric air. On the other hand, in some of the most simple forms of animal life, which, with the exception of some of the entozoa, are all aquatic, the function of respiration is effected by the external surface, and they have no special organ for exposing their nutritious juices to the action of the atmospheric air, no apparatus for bringing fresh supplies of the surrounding fluid into contact with their bodies, and no canals or tubes for securing a more rapid change of those portions of the nutritious juices exposed to the action of the atmospheric air.

Numerous and interesting modifications of the respiratory apparatus, each wonderfully adapted to the wants of the individual animal, and the medium in which it lives, and in admirable relation to its other nutritive functions, fill up the wide interval between the most complex and the simplest methods of carrying on the function of respiration. This, like the other functions of the body, is, in proportion to the energy of its manifestations, more concentrated upon individual organs chiefly or entirely constructed for this purpose, and it thus becomes more and more specialized as we ascend in the zoological scale.

The position of the respiratory apparatus is chiefly regulated by the circumstance of the animal being terrestrial or aquatic, or, in other words, by its supply of atmospheric air being in the gasiform condition, or held in solution by water. In the greater number of aquatic animals, the respiratory apparatus is placed on or near the external surface of the body; while, in the terrestrial animals, it is situated more or less deeply in the interior of the body. The medium in which the animal lives also influences the size and complexity of its respiratory organs. As the quantity of atmospheric air in contact with respiratory organs of the same extent of surface must be much smaller in aquatic than in terrestrial animals, a more extended respiratory organ is required in the former than in the latter to effect the same amount of respiration, just as a more extended digestive apparatus is required in herbivorous than in carnivorous animals to extract the same amount of nutritious matters from their food. As water cannot furnish to terrestrial animals an adequate supply of atmospheric air, their vital actions are brought to a stand when their respiratory organs are immersed in that fluid, and this the more quickly in those immediately dependant, as the birds and mammalia, upon large and frequent supplies of atmospheric air. The respiratory organs of aquatic animals are, on the other hand, inadequate for the performance of respiration in the atmospheric air, but from very different circumstances. The most obvious of these are, 1st, their respiratory organs, from their external position, are either freely exposed or only partially covered, so that when they are removed from the water into the atmosphere they become dry in consequence of the evaporation of their moisture, and this the more rapidly as there is little or no provision independent of the water in which they live, for keeping these surfaces moist by a secretion, as in air-breathing animals: 2dly, in those cases where the respiratory organ consists of numerous membranous plates or laminæ that float apart in the water, and have every portion of their external surface bathed in this fluid, removal into the atmospheric air causes them to fall together, so that comparatively a small quantity of their surface is now in contact with the air. In some of the Crustacea, and in some fishes, as the eels, the branchiæ, or respiratory organs, being covered to a great extent, desiccation proceeds slowly, and life may be prolonged for a considerable time in the atmospheric air. In one of the groups of the Crustaceans, the land-crabs or Gecarcinians, though the respiratory organs have a close resemblance to the branchiæ of the aquatic tribes, yet as they inhabit damp situations, and have a provision for keeping the respiratory surface moist, they are enabled to live as terrestrial animals.

It has already been stated that the respiratory apparatus in all the higher animals consists of three distinct parts;—of an expanded membrane, through which the atmospheric air and the nutritious fluid the blood, act chemically on each other; of organs for renewing the atmospheric air in contact with the external surface of this membrane; and of organs for circulating the nutritious fluid along channels placed upon the inner surface of this membrane. Of these three portions of the respiratory apparatus, the first, or the expanded membrane, which may be termed the *respiratory membrane*, is the most essential, and the other two may be considered as merely accessory to it. In those animals, as the Infusoria, the Polypes, &c., that have no special organs of respiration, the surfaces, bathed by the fluids in which they live, act as a *respiratory membrane:* the atmospheric air in the surrounding fluids is there brought into contact with the nutritious juices, and the function of respiration is effected in the feeble manner in which it is manifested in such animals. In those animals possessing special organs of respiration, the respiratory membrane is formed in almost all cases by prolongations, folds, or reduplications of the internal or external tegumentary membrane, and all of these different arrangements are evidently with the view of increasing the extent of surface of that membrane. In the pulmograde Medusæ the margin of the disk, though smooth, and presenting no prolongation of the external tegumentary membrane, acts more efficiently in the function of respiration than the other parts of the surfaces of the body, and may be considered as a respiratory organ, in consequence of a large quantity of the nutritious juices flowing through numerous vessels distributed there. In some of the Echinodermata, as in the star-fishes (*Asteridæ*), and in the sea-urchins (*Echi-*

*nidæ*), the internal integumentary membrane is materially aided in the performance of this function by the aquiferous canals in the former, and by the peritoneal cavity in the latter; indeed, the peritoneal cavity may be considered the special organ of respiration in the Echinidæ.

The respiratory membrane, in most cases, presents one of three forms, which have received the names of *gills* or *branchiæ*, of *tracheæ*, and of *lungs*. In the gills or branchiæ the tegumentary membrane is prolonged outwards, in the shape of laminæ, tufts, or branches; and this arrangement is found in aquatic animals. This form of the respiratory membrane is not, however, universal in those aquatic animals possessing special organs of respiration. In the Holothuridæ, one of the tribes of the Echinodermata, the chief respiratory organ consists of two aquiferous tubes, of an arborescent form, that open upon the surface of the cloaca.*

In the Ascidians, among the Mollusca, the chief respiratory organ is a large cavity, regarded by some as a dilatation of the œsophagus; and in certain of the aquatic Gasteropoda it consists of a sac, with lamellæ on its inner surface, opening upon the external surface of the body. The small cavities placed along the sides of the body of the leech, and opening externally, are also believed to be respiratory organs.

The arrangement of the respiratory membrane, termed tracheæ, is present in the Articulata, among the Myriapods, insects, spiders, and also, with a few exceptions, among the larvæ of insects living in the atmosphere; and is observed in greatest perfection in the adult insects. It consists of a prolongation of the external membrane into the interior of the body, in the form of tubes, often extensively subdivided and ramified, kept open by fibres rolled round their walls in a spiral manner, and commencing at the external surface of the body by orifices termed *stigmata*. In certain of the larvæ of insects, this arrangement of the respiratory membrane is modified to adapt it for aquatic respiration. In the larvæ of the Ephemera, these tracheæ, instead of terminating in stigmata, are prolonged outwards into a foliaceous expansion of the external integument, where they are subdivided and ramified, and terminate in shut extremities. A constant interchange between the air in the tracheæ of these larvæ, and the atmospheric air dissolved in the water, will go on through the membranes interposed between them.† In the larvæ of the Libella the tracheæ are distributed in a similar manner in a membrane placed within the anus, and the animals draw in and expel the water with considerable force from that cavity, so that these respiratory movements act at the same time in causing locomotion.

The arrangement of the respiratory membrane called *lungs* consists of the prolongation of the tegumentary membrane inwards in the form of sacs, and is destined for aërial respiration. In some of the terrestrial gasteropodous Mollusca, the lung is formed by a single, large, and simple sac, opening by an orifice on the right side of the body. In the Arachnida the lungs are composed of two or more separate cavities, lamellated on their interior, opening on the external surface of the body, and are analogous to the branchial cavity in some of the aquatic Gasteropoda. In all the air-breathing Vertebrata, the respiratory membrane is formed by a prolongation of the internal tegumentary or mucous membrane from the upper part of the digestive tube, and this also holds in the aquatic Vertebrata, or the fishes. When the expanded respiratory membrane is placed at some distance from that portion of the mucous membrane of the digestive tube with which it is continuous, as is especially the case in the Mammalia and birds, this mucous membrane is prolonged to the part where its expansion occurs, in the form of a tube, strengthened on the outer surface by elastic textures to enable it to withstand the atmospheric pressure. Along this tube (trachea), and its branches (bronchi and bronchial tubes), the air passes to and from the proper respiratory membrane on the inner surface of the lungs. In the water newt the lungs consist of a pair of elongated sacs, without any internal laminæ or folds. In the frog these membranous sacs present ridges on their inner surface, especially at the upper part; and in the lungs of the turtle and crocodile these ridges increase in number and in size, and form partitions dividing the interior of the lungs into numerous cells communicating with each other.

In birds the bronchial tubes on entering the lungs have numerous parietal cells on their inner surface; and this extension of the respiratory surface is still further increased by some of the tracheæ opening into membranous bags, often presenting a cellular appearance, and communicating with the interior of certain of the bones. In the lungs of man and the other Mammalia, the bronchial tubes divide and subdivide into minute branches, each of which ends in a cluster of terminal cells, forming one of the small lobes into which the lung may be divided. By this arrangement an immense extent of respiratory surface is packed up in a small space.*

* This form of the respiratory apparatus has been termed *cœlobranchiate* by Straus-Durckheim, being derived from κοῖλος, *hollow*; and βράγχια, *gill*.

† This modification of the tracheal respiratory organ has been designated *tracho-branchiate* by Straus-Durckheim.

* Hales (Statical Essays, vol. i. p. 242. 1769) estimates the inner surface of the whole lungs in the calf at 289 square feet, equal to 19 times the surface of a man's body; and Lieberkuhn calculates (as quoted by Schultz in his System der Circulation, p. 288) that the whole surface of the air-tubes and air-cells in the human species amounts to 1400 square feet. Monro, on the other hand (Essays of Monro Secundus, p. 59. Edinburgh, 1840) calculates that the inner surface of the human lungs is only equal to 440 square feet, or nearly thirty times

In those animals possessing special organs of respiration, this function is not necessarily restricted to these organs; on the other hand, there are generally other parts of the organism which serve as auxiliary organs of respiration. We have already seen that respiration may take place wherever the atmospheric air and the nutritious juices are not separated by tissues impermeable to gases. When these tissues are feebly permeable by gases, or when the quantity of nutritious juices in these tissues is small, their respiratory qualities must be feeble, however abundant the amount of atmospheric air in contact with them may be: while under more favourable physical conditions of the tissues, the amount of respiration effected may be considerable. We can readily understand, therefore, how the external cutaneous surface in fishes and in the batrachian reptiles may considerably assist the special organs of respiration; and how, in some fishes, the mucous surface of the digestive tube may act as an accessory organ of respiration when they rise to the surface of the water, and swallow a quantity of air. As in the crocodiles, and in certain cartilaginous fishes, there are apertures by which the water may enter the peritoneal cavity, it is believed that in these animals the large abdominal serous membrane, which is the chief respiratory organ in the Echinida, serves as an auxiliary organ of respiration.* In fishes the air-bladder, formed by a prolongation of the internal tegumentary membrane, and constituting a rudimentary lung, is generally considered to be an accessory respiratory organ. Even in the higher Mammalia, the external tegumentary membrane, and the internal tegumentary membrane of the digestive tube, but more especially the former, may be regarded as auxiliary organs of respiration, but the aid they afford to the special respiratory membrane in the lungs is so feeble, that in a practical point of view they may in most cases be disregarded, and they can under no circumstances supply the place, even for a brief period of time, of the special respiratory membrane.

A moist condition of the respiratory membrane appears to be essential to the proper performance of its functions, and this is obtained in those animals which breathe atmospheric air, by its deep position, and by the fluid secretions poured out upon its surface.

The structure of that portion of the respiratory apparatus which acts in bringing fresh supplies of atmospheric air into contact with the respiratory surface, is chiefly regulated by the animal being terrestrial or aquatic, and by the amount of respiration required. In many of the lower aquatic tribes the respiratory surface is external and floats in the water, and any movements on the part of the animal, and currents in the water, must change, more or less rapidly, the fluid in contact with the respiratory surface. In such cases, the only *structural* provision for promoting such movements in the water, is the presence of numerous cilia on the surface of the respiratory membrane, which by their incessant action produce currents in their neighbourhood. In those aquatic animals, where the respiratory organ assumes the form of branched tubes or of cavities, the water in their interior is constantly undergoing a gradual renewal by the incessant action of the cilia upon the inner surface, and it is at other times expelled or renewed much more rapidly by the action of the surrounding contractile tissues. In some of the Crustacea where the branchiæ are lodged in a cavity placed under the lateral portions of the carapace, the renewal of the water is effected by the movements of distinct appendages, belonging more especially to the masticatory and locomotive organs; and in the Cephalopoda, where the branchiæ are placed in a cavity beneath the mantle into which the rectum and generative organs also open, the water is chiefly renewed by the contractions of the mantle. In fishes, whose demand for atmospheric air is greater, a complicated apparatus of muscles, bones, and nerves is arranged around the branchiæ, for keeping up a constant stream of water over the respiratory membrane. In insects the air in the tracheæ is chiefly renewed by the contractions and dilatations of the abdominal segments of the body.

In all the vertebrata that breathe by lungs, the muscles for renewing the air in contact with the respiratory surface are numerous, are called into action involuntarily and by excitations conveyed through the nervous system, and contract more or less frequently according to the wants of the organism. In batrachian reptiles, where the ribs are wanting, and in chelonian reptiles whose ribs are soldered together and immovable, the air is not drawn into the lungs, as in birds and the Mammalia, by the dilatations of the walls of the cavity enclosing them, but it is forced into the lungs chiefly by the action of the muscles attached to the hyoid bone as by a forcing-pump, from which it is again expelled chiefly by the abdominal muscles, as in the Mammalia and birds.*

The manner in which the nutritious juices are carried to and from the respiratory membrane is usually regarded as a part of the function of the circulation, and has already been described in the article on that function. The position and extent of the respiratory membrane, and the degree of activity required of it, are the circumstances that chiefly influence the arrangement of this portion of the circulatory apparatus, and the quantity and velocity with which the nutritious juices are circulated through it. When the respira-

greater than that of the whole external surface of the body.

* In the Holothuria the tentacula appear to act as auxiliary respiratory organs. I have observed an active circulation of the nutritious juices in the tentacula of the Oenus brunneus of Forbes.

* Detailed accounts of the respiratory organs in the different divisions of the animal kingdom are given in the articles under these heads. See also the article PALMO, supplement.

tory membrane is closely packed in a particular part of the organism, and the function of respiration is at the same time energetic as in the Mammalia, the blood is circulated with great activity, and in great quantity, through vessels distributed in this membrane, and appropriated solely to this purpose. When the respiratory membrane is extensively diffused, as in insects, throughout the organism, and the atmospheric air is brought into contact with it in the different tissues, a particular set of canals for carrying the nutritious juices to and from the respiratory membrane is not required; and were we, in such animals, to examine the circulatory apparatus without any reference to the nature of the respiratory apparatus, we could not understand how a circulatory apparatus, apparently so imperfect, is yet equally efficient in carrying on the nutritive processes as in other animals where its mechanism is much more complicated.

*Apparatus for renewing the air in the lungs in the human species.*— In man, as in the other Mammalia, this consists of three distinct parts: — 1st, of a movable framework composed of articulated bones and cartilages, but chiefly of the former, termed the thorax; 2dly, of muscles for enlarging and diminishing the capacity of the thorax; 3dly, of nerves through which the movements of these muscles are excited and regulated. The uses of this apparatus are not, however, restricted to respiration. The bones of the thorax furnish a certain degree of protection to the lungs, heart, and other important parts enclosed by them; and during certain violent efforts of the voluntary muscles, as in lifting a weight, they are no longer mobile as in the respiratory movements, but are rendered fixed, and afford a firm and steady *point d'appui* to the powerful muscles passing between the external surface of the thorax and the thoracic extremities, during their contraction. The same muscles which act involuntarily in dilating and contracting the chest in respiration, are frequently engaged in the performance of voluntary muscular movements, as in articulate speech, straining, &c. They also, in connexion with other muscles, or even alone, perform various involuntary muscular movements which are not respiratory, as in the excito-motory movements of coughing, sneezing, defecation, and urination, and in the sensational and emotional involuntary muscular movements of laughter, sighing, yawning, vomiting, &c.

The thorax can be enlarged in all its diameters by the action of its muscles, — in the vertical or atlanto-sacral, in the antero-posterior or vertebro-sternal, and in the transverse. Its enlargement in the antero-posterior and transverse directions is effected by the elevation of the ribs, and its enlargement in the vertical direction by the descent of the diaphragm, and by the elevation of the upper part of the thorax, but chiefly by the former. As the ribs in the human species differ in length, in the degree of their inclination to the spine, in the form and extent of their curvature, in the manner in which the anterior extremities of their cartilages of prolongation terminate, and in some other anatomical points which must influence their mode of action, the phenomena attending the elevation of the ribs are not the same over all parts of the chest, but it will be sufficient for our present purpose to state the general effects of these movements.* As the osseous arches formed by the ribs are so inclined upon the vertebral column that their lower edges form acute angles with that column, and their anterior or sternal are placed lower than their vertebral ends, and as their vertebral or posterior ends have a very limited extent of motion †, their elevation brings them to or near the horizontal plane, and carries forward their sternal extremities; and as the greater number of the ribs are attached to the sternum through their cartilages of prolongation, this bone must by this movement be pushed forwards, and the antero-posterior diameter of the thorax be enlarged.

The transverse diameter of the thorax is increased by the circumstance that the ribs during their elevation do not simply ascend, but perform a slight rotation round an axis passing between their anterior and posterior extremities, by which two effects are produced; 1st, their lower, which form a segment of a somewhat larger circle than their upper edges, are turned somewhat outwards, and the upper slightly inwards, so that the concavities of the arches formed by the ribs are now perpendicular, or nearly so, to the median plane of the body, instead of being oblique as before their elevation; 2dly, the middle portion of the greater number of ribs, which before was placed below a straight line passing through their two extremities, in consequence of the shaft of the rib bending upwards near the sternal end at what has been termed the anterior angle, is now placed on the same plane with the two extremities, and the whole rib rendered horizontal. This rotatory motion is greater at the middle of certain of the ribs as they rotate upon their two extremities, so that each rib in the performance of this movement may be considered as forming two levers, the two extremities being the pivots, and the middle of the ribs the ends of the levers most remote from the pivots.‡ The forward movement of the sternum is greater at its lower than at its upper part, in consequence of the greater length and inclination of the lower vertebro-sternal or true ribs, and the greater length of their cartilages, and the more acute

* Mr. Sibson has lately (Philos. Transact. of London, Part IV. for 1846, p. 528) given an elaborate analysis of the movements of the thorax in respiration. Dr. Hutchinson has also lately (Medico-Chirurgical Transactions of London, vol. xxix. 1846, p. 183) published some of the results of his observations on this subject.

† According to the observations of Haller (Element. Physiologiæ, tom. iii. p. 23. 1766) the greatest movement at the vertebral extremity of a rib is scarcely the one-sixth part of a line.

‡ These observations do not apply to the inferior ribs, especially the two last or floating ribs, as they are depressed in inspiration, and not elevated.

angles formed by their articulation with the sternum; and this difference in the extent of movement in the two portions of the sternum must be still greater before the *manubrium* and the body of the bone are united by ossific matter.* Though this description of the movements of the sternum in respiration, which is that given by Haller †, has been called in question by some modern anatomists, there can be no doubt of its correctness, for it can be proved, by an appeal to the mechanism of the thorax, that, in the upward and forward movement of this bone, its upper and lower ends will pass through paths which differ considerably in their curvature and direction. ‡ Though Haller was wrong in maintaining that the first rib is almost immovable in these actions of the thoracic walls, yet there can be as little doubt that Magendie is in error in asserting that this is the most movable of all the ribs; for however favourable the nature of its vertebral articulation may be for motion, this is counteracted by the mode in which its cartilage of prolongation is united to the sternum. §

The position and form of the diaphragm is well adapted for enlarging, by its contraction, the vertical diameter of the thorax; and being placed in the most capacious part of the thorax, even a slight elongation of the vertical diameter there will add considerably to the area of its inner surface. The convex or upper surface of the diaphragm, in its relaxed state, projects upwards on each side of its central or cordiform tendon into the thorax, and is higher anteriorly than posteriorly, and on the right side than on the left. This cordiform tendon is made a fixed point for the arched fibres that run from it to the ribs during their contraction, since it is pulled upon from below and behind by the two crura of the diaphragm, and in front by the short muscular fibres which pass to it from the point of the sternum and the lower edges of the cartilages of the ribs. If the lower ribs have been previously rendered steady by the action of the quadrati lumborum and serrati postici inferiores muscles, the arched muscular fibres of the diaphragm have another fixed point during their contraction. As the heart rests on the upper surface of the cordiform tendon, and the base of the lungs on the upper portion of the arched part of the diaphragm, the descent of the arched muscular fibres and their change to the horizontal position, causes a considerable enlargement of that part of the chest occupied by the lungs, while the position of the heart is comparatively little affected when the respiratory movements are moderate; but during forcible inspiration the heart recedes deeper into the chest, and during expiration it again comes forward.* The vertical diameter of the chest may be increased in inspiration by the pulling up of its superior portion, by the strong muscles of the neck attached to it, at a time when the lower portion is prevented from ascending, but an increase in the vertical diameter by an elongation of its upper part must have a much less effect in enlarging its capacity than an elongation of its lower part seeing that the thorax is at least four times as large at its lower as at its upper end. In ordinary respiration, and when the body is at rest, the ribs move little in the male, and the muscular movements of inspiration are chiefly carried on by the diaphragm.†

The ribs are elevated, in ordinary respiration, by the levatores costarum, external and internal intercostal muscles ‡, and also, more

* During the elevation of the ribs the elastic cartilages of prolongation of the sternal ribs undergo a certain amount of torsion, and the angles they form with the sternum become less acute. The enlargement of the chest produced by the elevation of the ribs is greater in the antero-posterior than in the transverse diameter, and the enlargement in the transverse direction is much greater at the anterior than at the posterior portion of the chest, from the mode in which the ribs are articulated with the vertebral column.

† Haller (Mémoire sur plusieurs Phénomènes Importantes de la Respiration. Lausanne, 1758) found that the upper edge of the sternum was carried forwards 2½, and the lower end from 3 to 8 lines, in a moderate inspiration.

‡ Ward's Human Osteology, p. 212. 1838.

§ The elasticity of the cartilaginous and osseous portions of the walls of the thorax will afford considerable resistance to the muscles in dilating it during inspiration. From the results obtained in two experiments upon the chest after death, Dr. Hutchinson calculates (Medico-Chirur. Transact. of London, vol. xxix. p. 205. 1846) that the force which the muscles of inspiration have to overcome in ordinary breathing from this source is probably, at least, equal to about 100 lbs., and in deep inspiration to about 300 lbs. In these calculations the additional resistance from the elasticity of the lungs was not taken into account.

* In the article HEART, Vol. II. p. 578, in stating this circumstance, the word inspiration was inadvertently used for expiration, and *vice versâ*.

† Dr. Hutchinson (Medico-Chirurg. Transact. of London, vol. xxix. p. 187. 1846) by a delicate instrument measured the costal movement during ordinary respiration in healthy individuals of the male sex, and found it not to exceed from two to four tenths of a line. The costal movements in the female sex, especially at the upper part of the chest, are considerably more extensive. Dr. Hutchinson states that the difference between the circumference of an ordinary man's chest measured over the nipples in the two states of a deep inspiration and a deep expiration, amounts to 3 inches (Opus cit. p. 222); and Valentin, under the same circumstances, found the average difference in the circumference of the chest, measured over the *scrobiculus cordis*, in seven individuals of the male sex between 17½ and 33 years of age, to be 1 : 8·29 of the whole circumference. (Lehrbuch, &c. erster band, S. 541. 1844.) In old age, when the costal cartilages of prolongation become ossified, the mobility of the chest must be diminished.

‡ The mode of action of the intercostal muscles has been a subject of discussion since the time of Haller, — many entertaining the opinion of Haller, that both the internal and external sets act simultaneously as muscles of inspiration; some, that they are muscles of expiration; while others, again, assert that one set act during inspiration, and the other set during expiration. Those who maintain the last opinion are not agreed among themselves as to what set act as muscles of inspiration, and what as muscles of expiration. The mode of action of these muscles has lately been carefully examined by MM. Beau and Maissiat and Mr. Sibson (Opus cit.); and the two former (Archives Générales de Médecine, 4 série, tom. i. p. 268. 1843), conclude

especially in the female, by the scaleni muscles. When the respiration becomes hurried or more laboured, the diaphragm and the muscles that elevate the ribs not only act more vigorously in inspiration, but numerous other muscles, which may be termed auxiliary muscles of inspiration, act in unison with these.* In cases of great dyspnœa, as in a fit of asthma, the shoulders are fixed, the head is thrown back, and all the auxiliary muscles of inspiration are brought into violent action. When the shoulders are fixed by the action of the levatores anguli scapulæ, the rhombodei majores et minores, and the humeri also fixed by the scapulo-humeral muscles, or by the person grasping some fixed object by the hands, then the muscles, or portions of them which pass between the thoracic extremities and the anterior and lateral walls of the chest, as the serrati magni, the pectorales minores et majores, the subclavi, and perhaps the costal portion of the latissimi dorsi, act as muscles of inspiration, by pulling the ribs upwards and outwards † ; and when the head, cervical vertebræ, hyoid bone, and larynx are fixed by the numerous muscles capable of performing this action, then the sterno-cleido-mastoidei, the sterno-hyoid, and sterno-thyroid muscles, may aid the scaleni muscles in drawing the superior part of the thorax upwards.‡ The serrati postici superiores, and the cervicales descendentes, are also accessory muscles of inspiration, if the former be not, at times, in fact a muscle of ordinary inspiration. The superior aperture of the larynx is dilated during inspiration by the crico-arytenoidei postici muscles when the breathing is in the least hurried; and in laboured breathing the nostrils are expanded by the contraction of the muscles, which draw the alæ of the nostrils outward. The greater or less demand for fresh air in the lungs regulates the number of these accessory respiratory muscles brought into play, and the energy of their contraction.

A diminution of the capacity of the thorax or an act of expiration, by which part of the air is expelled from the lungs, follows immediately each inspiratory movement. In ordinary respiration, after the muscles of inspiration have ceased to contract, the elasticity of the thoracic walls, especially of the cartilaginous portion, causes it to return to the state in which it was before its dilatation; and when the contracted diaphragm has relaxed, the elasticity of the parts displaced by its descent, is sufficient, without much, if any, aid from the abdominal muscles, to push the diaphragm again upwards. The gas present in greater or less quantity in the digestive tube, being compressed during the descent of the diaphragm, will, from its elasticity, assist in pushing upwards the relaxed diaphragm.* In more forcible expirations, when the walls of the chest are compressed beyond the state they assume when the muscles of inspiration are relaxed, the compressing muscles experience considerable resistance from the elasticity of the walls of the chest.

When the expirations are performed more forcibly than ordinarily, the diaphragm is pushed up, and the sternum and ribs depressed by the contractions of the three broad muscles of the abdomen, by the recti abdominis, and by the triangularis sterni muscles. The levator ani, one of the antagonist muscles of the diaphragm, assists also in pushing the abdominal viscera upwards. In hurried or laboured expirations the diaphragm is pushed more forcibly upwards by the muscles mentioned, and the ribs are pulled downwards, and the chest compressed, by the quadrati lumborum, serrati postici inferiores †, sacro-lumbales and longissimi dorsi muscles.

MM. Beau and Maissiat ‡ have described three kinds of ordinary respiratory movements: 1. the abdominal, in which the abdominal walls chiefly act: 2. the costo-inferior, in which the movements chiefly take place in the lower ribs, from the seventh inclusive, downwards: 3. the costo-superior, in which the superior part of the chest is carried upwards by the elevation of the superior ribs and the sternum. The first kind, or the abdominal type, is observed in infants up to the end of the third year in both sexes; but after this period the costo-superior type in girls, and the costo-inferior and abdominal types in boys, generally prevail, and this difference becomes more marked as they advance in years. Almost all men, therefore, breathe by

that both sets are muscles of expiration, while the latter maintains the more probable opinion, that they act differently in different parts of the thorax. Dr. Hutchinson has also lately made some observations on the actions of these muscles in Medico-Chirurgical Transact. of London, vol. xxix. p. 213.

[Dr. Hutchinson regards the external intercostals and the intercostilaginous portion of the internal intercostals as muscles of inspiration, while the rest of the internal intercostals are muscles of expiration. See a further exposition of this author's views in the article THORAX. — ED.]

* According to Dr. Hutchinson (Opus cit. p. 187) the chief enlargement of the thoracic cavity in deep inspiration is made by the ribs, and *not* by the diaphragm.

†.Part of the muscles passing between the thoracic extremities and the anterior and lateral walls of the chest, here enumerated among the accessory muscles of inspiration, may, in certain cases, act as accessory muscles of expiration, by drawing the scapulæ forcibly downwards upon the ribs. (Vide observations of Mr. Sibson and MM. Beau and Maissiat.) These authors are not of the same opinion regarding the action of all these muscles; for, while the two former class the serratus magnus among the muscles of inspiration (Opus cit. tom. iii. p. 268. 1843), the latter affirms that the greater portion of its fasciculi acts visibly in violent expiration (Opus cit. p. 535): they agree, however, in placing the latissimus dorsi among the accessory muscles of expiration.

‡ The hyoid bone, larynx, and trachea are sometimes drawn downwards during violent inspirations by the strong contractions of the sterno-hyoid and sterno-thyroid muscles, causing a depression of these parts, at the same timo that they elevate the sternum.

* Maissiat, in his Etudes de Physique Animale, and Beau and Maissiat in Arch. Génér. de Méd. tom. iii. p. 263. 1843.

† Dr. Hutchinson informs us that the body is considerably shortened during violent expiration. (Op. cit. pp. 191, 192.)

‡ Archiv. Gén. de Méd. tom. xv. p. 399. 1842.

the lower part, and women by the upper part of their chest, and this independently of the effects of particular articles of dress! * This difference in the mode of respiration in the two sexes is, in general, maintained even in dyspnœa, unless it be very severe. As the costo-inferior and abdominal types of respiration would be impeded in the female when pregnant, the ordinary costo-superior type of respiration in the female has apparently a reference to that condition.†

Valentin ‡, Dr. Hutchinson §, and Mendelssohn ||, have lately made experiments upon the force of the muscular movements of inspiration and expiration. Those of Dr. Hutchinson are much the most extensive, and are 1500 in number. He found that the power of expiration is nearly one third stronger than that of inspiration; and he states that whenever the expiratory are not stronger than the inspiratory muscles, that some disease is present. He tested the force of the two classes of respiratory muscles by causing persons to make the most powerful efforts of which they were capable when breathing through the nose into an instrument constructed for the purpose, and the subjects of experiment were taken from individuals of the male sex, following very different occupations. In examining the results of the whole experiments, and including all the thirteen classes of men subjected to experiment, the power of the inspiratory muscles is found greatest in men of 5 feet 9 inches in height, their inspiratory power being equal, on an average, to a column of 2·75, and their expiratory power to 3·97 inches of mercury; while in four of these classes, composed generally of active, efficient, and healthy individuals, viz. Firemen, Metropolitan Police, Thames Police, and Royal Horse Guards, the inspiratory power of the men of 5 feet 7 inches was the greatest, being equal to 3·07 inches of mercury, and those of 5 feet 8 inches to 2 96 (nearly 3 inches). The average power of the 5 feet 7 inches and 5 feet 8 inches men of all the thirteen classes was only 2·65 inches of mercury. The inspiratory power of twelve six-feet men in the first battalion of Grenadier Guards was only 1·92 inches, while that of thirty-one of the same height in the Blues (Life Guards) was 2·71 inches. He infers from these experiments that a healthy man of 5 feet 7 inches or 5 feet 8 inches, should elevate by inspiration 3 inches of mercury. The force of the expiratory muscles is more liable to be affected by the ordinary occupation of the individual than that of the inspiratory muscles, and therefore the state of the former is less to be relied upon in judging of the health of the individual than that of the latter.* The elasticity of the walls of the chest is, no doubt, one cause of the greater force of the expiratory over that of the inspiratory muscles.

In inspiration the pressure of the elastic air in the lungs causes these organs to expand, so as to keep their outer surface in contact with the inner surface of the dilating thorax; and by this the air of the lungs becomes rarified, and a quantity of fresh air rushes along the trachea and bronchial tubes to restore its equilibrium; in expiration, on the other hand, the lungs are compressed, and a portion of air is forced outward along the same passages. In these movements the lungs are not quite passive. The external surface of the lungs, and of the numerous lobes into which they may be divided, is covered with an elastic membrane, and this, conjoined with the weight of their tissues, must favour the expulsion of the air during expiration, and present a certain amount of resistance to its entrance during inspiration.†

* These observations of Beau and Maissiat upon the differences in the respiratory movements in males and females are confirmed by Dr. Hutchinson (Op. cit. p. 195), and they were known so far to Boerhaave and Haller.

† These authors also state that this difference in the respiratory movements of the two sexes have impressed upon the chest certain anatomical differences; for while the intercostal spaces at the upper part of the chest are larger in the female, those at the lower part are larger in the male; and while the first rib is movable in the female, it is almost or entirely immovable in the male.

‡ Lehrbuch der Physiologie des Menchen, band i. S. 524. 1844.

§ Journal of the Statistical Society of London, vol. vii. p. 193. 1844; and Medico-Chirurg. Transactions of London, vol. xxix. p. 197. 1846.

|| Der Mechanismus der Respiration und Circulation, S. 116—120. Berlin, 1845.

* Valentin's experiments upon the respiratory forces were performed upon six males between 18 and 32 years of age. In ordinary tranquil respiration the force of each of the acts of inspiration and expiration was equal to the weight of a column of mercury of from 4 to 10 millimetres (or from ·1574 to ·3937 of an English inch); in the least forcible respiration it ranged between 20, 35, and 40 millimetres of mercury (from ·7874, 1·377, and 1·5748 of an English inch). In ordinary tranquil respiration in the same individual, at different periods, the range of the respiratory force was even more than between 5 and 10 millimetres (or between ·1968 and ·3937 of an inch). The average force of an ordinary tranquil respiration, when the nose was held and the individual inspired and expired through the mouth, was 6·45 mill. (·2539 of an inch); when they inspired through the nose and expired through the mouth alone, it was 10·6 mill. (·4173 of an inch); and when they inspired through the nose and expired through the nose and mouth, it was 5 mill. (·1968 of an inch), or about one half of the strength when they expired through the mouth alone. He found that the strongest inspiration of which these individuals were capable was equal to 144·3 mill. (5·6812 inches) of mercury, and the strongest expiration to 204 mill. (8·0316 inches) of mercury. Mendelssohn's experiments were performed upon seven individuals, and they breathed through one nostril, the other nostril and the mouth being shut. He found that the force of the most powerful expiration was greater than that of the most powerful inspiration by about one inch of mercury. The most powerful expirations were on an average between 4·4 and 4·8 inches of mercury. In performing such experiments it is necessary to breathe through the nose, the mouth being shut, as in those of Dr. Hutchinson and Mendelssohn, if we wish to obtain the force of the muscles of the chest, apart from that of those of the cheeks.

† Dr. Carson (Philos. Trans. of London for 1820, p. 42), states that in his experiments on "calves,

When the external air is admitted freely into the sac of the pleura, by an opening in the parietes of the thorax sufficiently large to permit the air to pass through it in greater quantities than it can enter the lungs by the trachea, the lung collapses rapidly and is compressed against the spine; and if this take place on both sides of the chest, the respiratory process is arrested, and the individual dies, as from suffocation. When the lungs lose their elasticity, and the air-cells become dilated and their septa partially broken down, as in emphysema, the respiratory membrane is not only diminished in extent, but expiration is more difficult, and when the chest is laid open after death, the lungs collapse imperfectly or not at all. It is evident that still more serious evils must follow interlobular emphysema, or effusion of air into the cellular tissue surrounding the smaller lobes of the lungs, if this occurs to a considerable extent.

Though the trachea, the bronchii, and even the smaller bronchial tubes are provided with distinct muscular fibres which can be thrown into contraction by direct excitation, and even, according to some experimenters, by excitation of their nerves, yet the notion entertained by many of the older, and even by some modern physiologists, that the lungs have an active power of contraction and dilatation synchronous with and aiding the movements of inspiration and expiration, is undoubtedly untenable. These muscular fibres of the bronchial tubes are endowed with that kind of contractility termed *simple contractility*, which manifests itself by more slow and prolonged contractions and relaxations than that of the voluntary muscles and the heart.* The possession of this property of simple contractility unfits these muscular fibres from acting simultaneously with the muscles of respiration moving the thorax, but fits them for effecting these changes on the capacity of the air-tubes, which may aid in the expulsion of substances from their interior, as in coughing. The movements of the cilia placed on the inner surface of the respiratory organs, can assist little, if at all, in renewing the atmospheric air in the lungs. The passage of the air into and from the lung, has an important effect upon the muscular respiratory movements. When a lung, or a considerable portion of it, is prevented from expanding by disease or any other cause, the pressure of the air on the inner surface of that portion of the chest covering the unexpansible lung is not now exercised during its dilatation; in other words, this portion of the chest in expanding must do so in opposition to the whole of the atmospheric pressure on its outer surface, amounting to 15 pounds on the square inch. This pressure appears to be too great for the muscles of inspiration, acting upon that part of the chest, to overcome, for the ribs are there motionless or nearly so, and if the lung is in a state of collapse, the walls of the thorax covering it fall in.

The muscular movements of inspiration and expiration are, in the natural and healthy state of the body, performed without the intervention of volition, and even without our consciousness, and belong to the class of movements which have lately received the appellation of excito-motary. When, however, the free aeration of the blood in the lungs is impeded, a sensation, urgent and imperious in its demands, is felt, which in our language is somewhat clumsily designated "the sensation of the want of fresh air in the lungs," and more elegantly in French, *le besoin de respirer*. These respiratory movements, therefore, depend upon the transmission inwards of certain excitations along afferent nerves to the central organs of the nervous system, whence a motive influence is sent outwards along the motor or efferent nerves distributed in the muscles to be moved. One of the principal excitor or afferent nerves of respiration is the par vagum; and the medulla oblongata is the portion of the central organs of the nervous system to which all the excitations of the nervous system capable of producing a respiratory muscular movement must be brought. The motor or efferent nerves that convey outwards from the medulla oblongata the motive influence which stimulates the muscles of respiration to contract are the phrenic, and part of the anterior roots of the dorsal and lumbar spinal nerves, the recurrent laryngeal, the portio dura, the spinal accessory, and some branches of the cervical and upper part of the axillary plexus besides the phrenic, especially the branch distributed in the serratus magnus muscle, termed by Sir Charles Bell the *external respiratory*. Some of these efferent nerves, like the muscles in which they are distributed, are habitually engaged in carrying on the respiratory muscular movements, while others aid these only when the respiration requires to be carried on more vigorously than usual.

We have already pointed out the extent to which the nervus vagus acts in conveying to the central organs of the nervous system those impressions that excite the *besoin de respirer* and the muscular movements of inspiration. (*Vide* art. PAR VAGUM.)

It is impossible to determine whether or not the pulmonary ganglionic nerves can convey inwards to the central organs of the nervous system impressions capable of exciting the respiratory muscular movements; but that impressions capable of exciting such movements to a certain extent may be re-

sheep, and large dogs, the resiliency of the lungs was found to be balanced by a column of water varying in height from one foot to a foot and a half, and in rabbits and cats by a column of water varying in height from six to ten inches." Vide also Observations by M. P. Berard on the Effects of the Elasticity of the Lungs, in Archives Génér. de Médecine, tom. xxii. p. 180. 1830.

* Vide experiments of Wedemeyer (Untersuchungen über den Kreislauf, p. 70), and of Dr. C. J. B. Williams (Transact. of British Scient. Assoc. for 1840, p. 411), upon the contractility of the bronchial tubes.

ceived by other nerves than those distributed in the lungs, is proved by the fact, which we have witnessed, that a few distinct respiratory movements may be observed in an animal after its lungs have been removed. That portions of the posterior roots of the spinal nerves distributed in the external cutaneous surface do act as excitors of respiration under certain circumstances, is proved by the effects of dashing cold water on the surface of the body, especially on the face. It is also probable that the circulation of venous blood in the arteries of the medulla oblongata may also cause the transmission of the motive influence outwards to the respiratory muscles. What are the excitations which lead to the performance of the muscular movements of expiration? Do the same excitations that occasion the muscular movements of inspiration, operate in the production of the expiration which immediately follows, so that they are to be considered two stages of the one and the same muscular action? These are questions which we are not prepared to answer. When the functions of the medulla oblongata are arrested, the motive influence of volition cannot pass downwards from the encephalon to the motor nerves that move the chest in respiration; and as all the excited or involuntary movements of respiration of the same muscles must, for the reasons already stated, instantly cease, immediate death is the consequence. Destruction of a portion of the spinal chord below the medulla oblongata and above the origin of the phrenic nerve will also produce the same result, for though the excitations that lead to the performance of the respiratory muscular movements reach the medulla oblongata, the motive influence cannot pass downwards to reach the motor nerves distributed in the muscles which act on the thorax.

*Frequency of the respiratory muscular movements.* — The frequency of the respirations varies in different individuals, and at different ages, and is so much influenced by the condition of the body and the mind at the time, even when the individual is in perfect health, that it is a much more difficult matter to determine their average frequency than may at first be imagined. Quetelet * has constructed the following table on the frequency of the respirations, at different ages, per minute, from observations made on 300 individuals.

| | Inspirations. | | |
|---|---|---|---|
| | Average. | Max. | Min. |
| At birth | 44 | 70 | 23 |
| 5 years | 26 | 32 | |
| 15—20 | 20 | 24 | 16 |
| 20—25 | 18·7 | 24 | 14 |
| 25—30 | 16 | 21 | 15 |
| 30—50 | 18·1 | 23 | 11 |

* Sur l'Homme et le Développement de ses Facultés, &c. tom. ii. p. 91. Bruxelles, 1836.

Mr. Hutchinson * gives the following table of the number of respirations per minute in adults when in the sitting posture, in 1714 adults of the male sex, considered to be in a state of health.

| Number of Respirations per Minute. | Number of Cases. | Number of Respirations per Minute. | Number of Cases. |
|---|---|---|---|
| 6 | 1 | 26 | 8 |
| 9 | 1 | 27 | 2 |
| 10 | 2 | 28 | 30 |
| 11 | 1 | 29 | 2 |
| 12 | 19 | 30 | 6 |
| 13 | 10 | 31 | 0 |
| 14 | 21 | 32 | 6 |
| 15 | 12 | 33 | 0 |
| 16 | 216 | 34 | 1 |
| 17 | 95 | 35 | 0 |
| 18 | 181 | 36 | 1 |
| 19 | 70 | 37 | 0 |
| 20 | 510 | 38 | 0 |
| 21 | 120 | 39 | 1 |
| 22 | 136 | 41 | 1 |
| 23 | 41 | | |
| 24 | 220 | Total | 1714 |
| 25 | 16 | | |

From Mr. Hutchinson's table it would appear that the majority of male adults breathe between 16 and 24 times per minute, and that of these a great number make 20 respirations per minute.†

According to Prevost and Dumas ‡, the ratio of the respirations to the pulsations of the heart is as 1 to 4. According to Mr. Hutchinson §, "the prevailing numbers run as four beats of the heart to one respiration." Quetelet || states, that "it does not appear that there is

* Medico-Chirurgical Transactions of London, vol. xxix. p. 226. 1846.

† The following results upon the frequency of the respiration in a state of rest have been obtained by others; but as these were made upon their *own persons*, they possess only the value of individual cases. Dalton (Memoirs of the Literary and Philosophical Society of Manchester, 2nd series, vol. ii. p. 26, 1813) found the number of his respirations to be 20 per minute; Thomson (System of Chemistry, vol. iv. p. 604, 1820), to be 19; Sir H. Davy (Researches chiefly concerning Nitrous Oxide and its Respiration, p. 434, 1800), to be 26 or 27; Magendie (Compendium of Physiology, translated by Milligen, p. 390, 1831), to be 15; Dunglisson (Human Physiology, vol. ii.), to be 16; and Allen and Pepys, on one of themselves (Philos. Trans. of London for 1808), to be 19. Menzies (Tentamen Physiol. Inaug. de Respiratione, 1790), found them to be 14 in the minute in the person on whom he experimented; Vierordt (Article "Respiration", in Wagner's Handwörterbuch der Physiologie, band ii. S. 834), in his own person, found them on an average to be $11\frac{9}{10}$ when sitting, and the mind disengaged; while their maximum was 15, and their minimum 9. Dr. Guy (Hooper's Vade-Mecum, edited by Dr. Guy) ascertained that the respirations in his own person were 22 in a minute while standing, 19 when sitting, and 13 when in the recumbent position.

‡ Vide Burdach's Traité de Physiologie, traduit de l'Allemand par Jourdan, tom. vii. p. 38. 1837.

§ Journal of the Statistical Society of London, vol. vii. p. 205.

|| Op. cit.

a determinate ratio between the pulsations and respirations; however, in many individuals, and I am of the number, it is as 1 to 4." Dr. C. Hooker* informs us that, from numerous careful observations, he has arrived at the conclusion, that the numerical relation between the beats of the heart and the respirations (except in infancy) is as 1 to 4½, and that any marked deviation from this relation indicates some mechanical or structural impediment to the free play of the lungs. According to Burdach†, the same circumstances which diminish the frequency of one of these movements acts equally upon the other; but it is proved by the recent observations of Dr. Guy, that these variations do not bear the same proportion to each other. In Dr. Guy's experiments‡, the proportion between the respirations and the pulse has varied from 1 : 2·60 to 1 : 5·23; and whereas the pulse becomes less frequent as the day advances, the respiration increases in frequency, so that there are 18 respirations in the evening for 17 in the morning. The chief cause of the variation in the ratio of the respirations and the pulse "is the position of the body. Thus, for a pulse of 64, the proportion standing was 1 : 2·95; sitting, 1 : 3·35; and lying, 1 : 4·97. In the sitting posture, but from different frequencies of the pulse, it has varied from 1 : 2·61 to 1 : 5·00. The proportions morning and evening for the same frequency of the pulse are about 1 : 3·60 and 1 : 3·40. The proportions which the respiration bears to the pulse decreases as the pulse increases. Thus, for a pulse of 54 the proportion was 1 : 3, for a pulse of 72 it was 1 : 4."

*Quantity of air drawn into the lungs at each inspiration, and expelled at each expiration; and the quantity of air in the lungs at different times.* — During ordinary respiration in a state of health, and when the body is at rest, a small quantity only of the air which the lungs can contain is exchanged by each act of inspiration and expiration. The average amount of air in the lungs in the state of ordinary respiration, may be considerably increased or diminished by forced inspirations and expirations, but the whole air contained in the lungs cannot be expelled by the most powerful action of the muscles of expiration. The quantity of air drawn into the lungs by each inspiration and again expelled by expiration, in the state of ordinary respiration, not only varies in different individuals, but in the same individual in different conditions of the body, so that the results obtained by physiologists on this point must necessarily be dissimilar, and the more especially as the greater number of these have experimented only upon a single, or a very limited number of individuals. The difficulty of ascertaining the average quantity of air exhaled at an ordinary expiration, and the great range that occurs in this respect, may be judged of by the statement of Vierordt, that the variation in his own person is as great as 1 : 4·75.* The probable average quantity of air drawn into the lungs at each inspiration even in healthy individuals, at different ages and in different states of the body and of the physical conditions under which it may be placed, can only be ascertained by the performance of a much more extended series of experiments than we at present possess; and the ascertainment of the causes which determine these variations from the average quantity will be still more difficult, and of still more importance. All such experiments are liable to many sources of fallacy, both from imperfections in the instruments used in conducting them, and from the muscular movements of respiration being unwittingly influenced by the attention of the persons experimented upon being fixed upon these movements; but the later experiments on this point are more trust-worthy than the earlier, as the instruments employed are better suited for the purpose, and by frequently repeating the experiment on the same persons, they at last become accustomed to the artificial circumstances under which they are placed, and they breathe more naturally.

Herbst, from his experiments, concluded, that a healthy adult of average size should in an ordinary inspiration inhale from 20 to 25 Parisian cubic inches (24·211 to 30·263 English cubic inches), and exhale the same quantity in expiration; while an individual of a feebler constitution of body should inhale from 16 to 18 Parisian cubic inches (19·368 to 21·789 English cubic inches).† Valentin gives as the result of his experiments upon seven males between 17½ and 33 years of age, that the quantity of air expired in ordinary up to a somewhat quickened respiration, ranges between 239·3 and 1567·7 cubic centimetres (14·603 and 95·672 English cubic inches), the average of which was 655·11 c. c. (40·081 English cubic inches).‡ Vierordt§, in repeated experiments upon himself, ascertained that at each expiration, when in a state of rest, he expelled from the lungs on an average 507 cubic centimetres (30·940 English cubic inches), and that the average of the five highest values was 699 c. c. (42·657 E. c. inches), and of the lowest 177 c. c. (10·801 E. c. inches).‖ Bourgery, from experiments upon

* Boston Medical and Surgical Journal for 1838. Vide also British and Foreign Medical Review, vol. vii. p. 263.

† Op. cit. p. 39.

‡ Hooper's Vade-Mecum, edited by Dr. Guy, pp. 131, 132. 1846.

* Wagner's Handwörterbuch der Physiologie, band ii. s. 836.

† Meckel's Archiv für Anatomie und Physiologie, band xiii. S. 83. 1828.

‡ Lehrbuch der Physiologie, band i. S. 538. These calculations of Valentin rest on the supposition that the expired air is *fully* saturated with moisture — a supposition invalidated by the experiments of Moleschott.

§ Wagner's Handwörterbuch der Physiologie, band ii. S. 835. Vierordt elsewhere states that he is of the middle height, and has no particularly roomy chest, was 59 kilogrammes in weight and 25 years of age when he performed his experiments.

‖ The following estimates have been drawn from a limited number of experiments upon a single individual, or upon a very small number of in-

fifty males and twenty females*, with the view of ascertaining the relation between the intimate anatomical structure of the lungs, and the functional capacity of these organs in the two sexes, concludes that the volume of air required by an individual in ordinary respiration augments gradually with the age, being least in youth (from 5 to 15 years), in consequence of the extreme vascularity of the lungs; increased from 15 to 30 years of age, in consequence of the proportional diminution in the closeness of the pulmonary capillary network of blood vessels; and to a much greater amount in old age, in consequence of the more rapid diminution of the extent of the respiratory membrane, which begins to take place after the lungs have arrived at their full development, or the age of 30.

It is obvious that we are not yet in possession of data to enable us to venture upon an estimate of the *average* quantity of air inspired and expired at an ordinary respiration, when the body is at rest and the mind undisturbed, at different periods of life, in the two sexes, and in different physical configurations of body. It is equally apparent that this is liable to considerable variation, and that the different results obtained by most experimenters,—setting aside those where an obviously faulty method was pursued,—depends as much upon the inherent differences in the extent of the respiratory movements in the individuals experimented upon, as upon errors in the mode of experimenting, and that the chief error committed by some of them consists in deducing averages from the few and insufficient experiments performed by themselves, and casting doubts upon the results obtained by others, simply because they do not accord with their own. It also necessarily follows that we are not in a position to form an estimate of the *average* quantity of air which passes out and in from the lungs in twenty-four hours in ordinary respiration. Vierordt*, from experiments on his own person, calculates that he respires 6034 cub. cent. (368·074 English c. inches) of atmospheric air in one minute, or 8,688,960 cub. cent. (530,026·560 Eng. c. in.) in the twenty-four hours. As, however, the respiration is rendered more energetic by speaking, walking, &c., any estimate drawn, as this by Vierordt is, from observations made when the body was in a state of rest, will be, as he was aware, too low; and proceeding on some of the results of Scharling's experiments, he makes allowances for this increase, and estimates the quantity of air respired in the twenty-four hours at 624,087·401 English cubic inches. Valentin † calculates that in his own person, after making allowances for temperature and watery vapour, he respires 469·9755 litres (28681·1948 English cubic inches) in an hour, and 688,348·6761 Eng. cubic inches, or nearly 398½ cubic feet of atmospheric air in the twenty-four hours.‡

The quantity of air drawn into the lungs during *quickened* or *forced* inspiration, and again expelled during expiration, also varies very considerably in different individuals of the same age. Sir H. Davy §, in many experiments upon himself, ascertained that at a temperature from 58° to 62° Fahr. he threw out of his lungs by a full forced expiration,

| | Cubic Inches. |
|---|---|
| After a full voluntary inspiration, from | 189 to 191 |
| After a natural inspiration, from | 78 — 79 |
| After a natural expiration, from | 67 — 68 |

So that, making corrections for temperature, he calculates that his lungs, in a state of voluntary or forced inspiration, contained about 254 cubic inches; in a state of natural in-

dividuals, and are therefore of little value in enabling us to ascertain the *average* quantity of air taken into the lungs and again expelled in ordinary respiration. Besides, some of these experiments are liable to obvious objections. Borelli (De Motu Animalium, Pars Secunda, p. 118. Lugdani, 1685) who appears to have been the first who attempted to ascertain this by experiment, estimates it at 15 cubic inches. Turin (Diss. p. 41, 42, as quoted by Haller), from experiments on his own person, at 40 cubic inches; and this is the estimate also formed by Menzies (op. cit. p. 28,) from his experiments. Goodwyn (The Connexion of Life with Respiration, &c., p. 36. 1788), from experiments on three individuals, estimates the quantity inspired at 12 cubic inches, which he supposes to be increased to 14 in the lungs by the increase of temperature. Sir H. Davy (Researches Chemical and Philosophical, &c., p. 433, 1800) informs us that he threw out of his lungs at each ordinary inspiration nearly 13 cubic inches; Mr. Abernethy (Surgical and Physiological Essays, Part II. p. 142, 1793), that he inspired 12 cubic inches; Dalton (Memoirs of the Literary and Philosophical Society of Manchester, 2nd Series, vol. ii. p. 26), also from experiments on his own person, estimates an ordinary inspiration at 30 cubic inches; Allen and Pepys (London Phil. Trans. for 1808), from experiments on one individual, at 16½ cubic inches; and Thomson (Animal Chemistry, p. 612. 1843) estimates his own inspirations at 16 cubic inches.

* Archiv. Général. de Méd. 4e Série, tom. i. p. 375, 1843, and Comptes Rendus, 23 Janvier, p. 182. 1843.

* Op. cit. pp. 856, 857.

† Op. cit. p. 570. The effects of exercise, digestion, &c., are included in this estimate.

‡ Mr. Coathupe (London and Edinburgh Phil. Magaz. vol. xiv. p. 401, 1839), from experiments on his own person in a state of rest, estimates the number of respirations at 20 in the minute, the average bulk of each respiration at 16 cubic inches, and the quantity of air that passes through the lungs in 24 hours, at 460,800 cubic inches, or 266·66 cubic feet. Mr. Coathupe's estimate agrees pretty closely with that of Dumas (Statique Chimique des Etres Organisés, 3e edit. p. 87), also formed from experiments on his own person, in a state of rest.

The estimate of the quantity of air that passes through the lungs, given by Bostock (System of Physiology, p. 321, 1836) is in all probability above the average. He proceeds on the supposition that in ordinary respiration a man respires 40 cubic inches of air 20 times in a minute, so that he makes the quantity respired in the 24 hours, 1,152,000 cubic inches or about 666½ cubic feet. It is probable that between 25 and 30 cubic inches of air for each ordinary inspiration will be found to be near the average in an adult male when in a state of rest.

§ Researches Chemical and Philosophical, &c., p. 410. 1800.

spiration about 135; in a state of natural expiration about 118; and in a state of forced expiration 41.* Goodwyn†, in his experiments on the capacity of the lungs upon four individuals after a natural death, found the residual air in the lungs to vary from 90 to 125 cubic inches, giving an average of 109, and as the chest, after a natural death, may be regarded as in a state of natural or ordinary expiration, this result differs very little from that of Davy. Allen and Pepys‡, in one experiment on the capacity of the lungs in a middle-sized man after death, also obtained a little more than 100 cubic inches of residual air. Vierordt§ supposes that the residual air in the lungs, after the *deepest* expiration, is about 600 cub. cent. (36·600 Eng. cub. in.), which differs but little from the estimate of Davy.

Herbst‖ made experiments upon 11 males, between 16 and 30 years of age, with the view of ascertaining the quantity of air drawn into the lungs in forced inspiration. The smallest quantity observed was in a Jew aged 22, of small stature, and feeble muscular system. He inspired between 60 and 70 Parisian cubic inches (between 72·635 and 84·738 Eng. cub. in.) after an ordinary expiration; between 102 and 118 (123·476 and 142·844 Eng. cub. in.) after a strong expiration; and 120 (145·266 Eng. cub. in.) after the strongest expiration. The largest quantity inspired was by a young man of 25 years, of middle height with a broad chest and large and powerful muscles, who inspired by a forced inspiration, about 169½ English cubic inches, without any previous voluntary expiration; about 290½ after a strong expiration; and about 290½ or 295⅓ after the strongest expiration. A young man of 23 years of age, 6 feet high, with broad chest and large muscles, inspired, without any previous voluntary expiration, 121 English cubic inches, and 280·72 after the fullest expiration. The quantities of air drawn into the lungs in forced inspiration in the other eight males, were intermediate between the highest and lowest mentioned above, and the average was about 202 English cubic inches.¶ Herbst also satisfied himself that the lungs of females have a considerably smaller capacity for air than those of males. He states that robust females, about the age of 30, may inspire without a previous voluntary expiration, 72½ English cubic inches, after an ordinary expiration nearly 109, and after the strongest expiration, from about 157⅓ to 174⅓ English cubic inches.* Herbst had an opportunity, in two of these experiments on males, of ascertaining the effects of tight clothing on the extent of the respiratory movements. One individual who inspired 128 and another 116·16 English cubic inches, without a previous expiration after the clothes were loosened, could before this only inspire 96·80 and 60½ English cubic inches.† The most extensive experiments by far, made with the view of ascertaining the quantity of air which can be thrown out of the lungs by forced expiration, after the deepest inspiration, are those of Mr. Hutchinson.‡ These experiments were performed upon 1923 males, and they were made to breathe into an instrument constructed for the purpose, and which he has called a *spirometer*. He has inferred from the data he has collected on this point, the rule, that "for every inch of height (from 5 feet to 6) 8 additional cubic inches of air at 60° Fahr. are given out by a forced expiration;" so that he believes that from the height alone of an adult male, he can tell what *quantity* of air he should breathe to constitute him healthy, and that this method may be turned to important practical application in ascertaining disease of the lungs,

* Sir H. Davy states that this capacity is most probably below the medium, as his chest was narrow.

† Op. cit. p. 26.

‡ Philos. Trans. of London, 1809.

§ Op. cit. p. 892.

‖ Op. cit. p. 98.

¶ Herbst found that a boy of 15 years inspired 116·16 English cubic inches after a strong expiration, and expired the same quantity after a full inspiration. Another boy of 13 years, but of the size of one of 15, likewise expired 116·16, while a boy of 11 years inspired without a previous expiration, 36·30; after a strong expiration he inspired 72·60 English cubic inches, and expired the same quantity after a full inspiration.

* Bourgery (op. cit.) states, that in well formed and healthy individuals, a man at 30 will, by a forced inspiration, draw into the lungs 2·50 to 4·30 litres (or 152·567 to 262·416 English cubic inches), and a woman from 1·10 to 2·20 litres (or 67·129 to 134·259 English cubic inches), and has inferred from his experiments, that at the same age the amount of forced respiration of the male doubles that of the female, and this conclusion accords with the results of Mr. Thackrah (The Effects of Arts, Trades, and Professions, &c., on Health and Longevity, 2nd edit. p. 181, 1832), who states that "extensive examination shows us that, while healthy men exhale by the pulmometer 200 cubic inches and upwards, women rarely exceed 100, and often do not reach that amount." Mr. Thackrah supposes that this difference is due, to a considerable extent, to tight lacing by females.

† The condition of the stomach as to fulness, also affects the extent of the respiratory muscular movements. Mr. Hutchinson says, "I have found a dinner diminish the vital capacity (by which he means the greatest voluntary expiration following the deepest inspiration) to the extent of 12 and even 20 cubic inches." The position of the body has also, according to Mr. Hutchinson (opus cit. p. 197), a considerable effect upon the vital capacity of the chest. In experiments upon himself he found that when standing he could throw out 260 cubic inches; sitting, 255; and when recumbent (supine), 230, (prone) 220, so that position effected a difference of 40 cubic inches. In a fit of dyspnœa a person can breathe easier in the erect or sitting than in the recumbent posture, as the dorsal movements that attend difficult respiration, are freer in the former than in the latter position.

‡ Journal of the Statistical Society of London, vol. vii. 1844, and Medico-Chirurgical Transactions of London, vol. xxix. p. 137. 1846. The memoir in the last publication contains a more extensive series of experiments than that in the former. These researches would require to be still farther extended upon both sexes at the various periods of life, and under varied circumstances, before they can yield all the information on this subject that is desirable.

under circumstances where the ordinary methods fail. Mr. Hutchinson has given the following table to show the quantity of air expelled by the strongest expiration after the deepest inspiration for every inch of height between 5 and 6 feet, as ascertained by actual experiment (column 1) by his *spirometer*, and as calculated according to the rule mentioned above (column 2).

| Height. | From Observation. | Regular Progression. |
|---|---|---|
| ft. in. ft. in. | cub. in. | cub. in. |
| 5 0 to 5 1 | 174 | 174 |
| 5 1 — 5 2 | 177 | 182 |
| 5 2 — 5 3 | 189 | 190 |
| 5 3 — 5 4 | 193 | 198 |
| 5 4 — 5 5 | 201 | 206 |
| 5 5 — 5 6 | 214 | 214 |
| 5 6 — 5 7 | 229 | 222 |
| 5 7 — 5 8 | 228 | 230 |
| 5 8 — 5 9 | 237 | 238 |
| 5 9 — 5 10 | 246 | 246 |
| 5 10 — 5 11 | 247 | 254 |
| 5 11 — 6 0 | 259 | 262* |

Mr. Hutchinson has found that two other conditions of the body besides the height, regulate the quantity of air that passes to and from the lungs in forced voluntary respiration, and these are age and weight. He states that weight does not affect the respiratory power of an individual of any height between 5 feet 1 inch and 5 feet 11 inches until it has increased 7 per cent. above the average weight of the body in persons of that height, but beyond this it diminishes in the relation of 1 cubic inch per pound for the next 35 pounds—the limit of the calculation. In males of the same height the respiratory power is increased from 15 up to 35 years of age, but from 35 to 65 years it decreases nearly $1\frac{1}{2}$ cubic inch for each year.† Bourgery concludes from his experiments already referred to, that the measure of respiration (by which he apparently means the quantity of air which may be drawn into the lungs by a forced inspiration) is greater the younger and thinner the person is; that its maximum in both sexes occurs at the age of 30; that the relation of a forced and ordinary respiration diminishes with the age of the individual, being, he says, from 1 to 12 at three years of age, as 1 to 10 at fifteen, as 1 to 9 at twenty, as 1 to 3 at sixty, and as 1 to $\frac{1}{2}$ or $\frac{1}{3}$ at eighty years; whence it follows that in youth there is an immense respiratory power in reserve for any violent exertion, while in old age the individual under such circumstances is at once out of breath.*

*Changes upon the atmospheric air in respiration.*—One of the most obvious changes, under ordinary circumstances, upon the air that enters the lungs in respiration is an increase of its temperature, and consequently an augmentation of its bulk. As a quantity of water is readily supplied by the fluid secretions of the inner surface of the air-passages, and by the blood in the pulmonary capillary blood-vessels, this augmentation of the temperature of the air is also necessarily attended by an increase of its watery vapour, and consequently by an additional increase in its bulk and elasticity. The expired air, therefore, contains more caloric, more watery vapour, is more elastic, and is of less specific gravity than the inspired air. Valentin performed 12 experiments on his own person by breathing through an apparatus invented by Brunner and himself, to ascertain the temperature of the expired air, and he obtained the following results. In breathing atmospheric air of a temperature varying from 8°·5 to 33°·5 Reaumur (51°·125 to 107°·375 Fah.), he observed a difference of 1°·75 R. (3°·937 F.) in the temperature of the expired air. While breathing in the lowest temperature, viz. 51°·125 F., the temperature of the expired air was 96°·687 F., and was warmer than the inspired air by 45°·562 F.; and when breathing in the highest temperature the expired was colder

* Med.-Chir. Trans. vol. xxix. p. 237. Experiments to ascertain the quantity of air that may be inspired or expired in forced respiration have also been performed by Hales (Statical Essays, vol. i. p. 243), Jurin, Menzies, Goodwyn, Dr. Bostock (System of Physiology, p. 316. 1836), Dalton (Opus cit. p. 26), Thomson (Animal Chemistry, p. 610. 1843), Valentin (Opus cit. p. 540), and Thackrah (The Effects of Arts, Trades, and Professions, &c. on Health and Longevity, 2nd edit. pp. 27, 30, 64, 76, 98, 181, and 182). These experiments, however, are neither sufficiently numerous — several of them having been performed on a single individual only,—nor are they accompanied with the details necessary to enable us to contrast them with those of Mr. Hutchinson; but the results obtained in the greater number of these do not differ much from those of Mr. Hutchinson upon men of middle stature. Valentin experimented on six males, and his estimates rest on the questionable supposition that the expired air is fully saturated with moisture. Thomson experimented on 11 males and 1 female, from 14 to 33 years of age; and Mr. Thackrah's experiments were considerably more extensive, and were made on individuals of different trades and professions.

† Mr. Hutchinson has not observed any direct relation between the circumference of the chest and the respiratory power or what he terms the vital capacity. According to the experiments of Herbst (Opus cit. p. 104), and Mr. Hutchinson, the mode of determining the quantity of air which the lungs are capable of containing during life in any particular case, by measuring after death the quantity of air which can be thrown into them by inflation, is fallacious. This is probably chiefly due to the congestion of the depending parts of the lungs by blood, so frequently found after death. Both Herbst and Mr. Hutchinson have performed experiments to show the extent to which the quantity of air in forced respiration is diminished in *phthisis*.

* Among the proofs of these conclusions, advanced by Bourgery, it is stated by him that the measure of respiration of a boy of 15 years of age is 2 litres (122·054 Eng. cubic inches), and a man of 80 years 1·35 litre (82·386 Eng. cubic inches): that while a boy of 10 years and a man of 80 inspire by a forced inspiration the same quantity of air, viz. 1·35 litre, yet the *ordinary* respiration of the former is only 1 decilitre (6·102 Eng. cub. in.), while that of the latter is 9 decilitres (54·918 Eng. cub. in.); so that with a mass three times smaller, the child possesses an energy of hematose eight times greater.

than the inspired air by $6^{\circ}\cdot 75$ F. In the last experiment, though the inspired air was $7^{\circ}\cdot 875$ F. warmer than the internal temperature of the body, the expired air was only about $1^{\circ}\cdot 125$ F. warmer than what it is when air of the ordinary temperature is breathed. The average temperature of the expired air is, according to Valentin, $99^{\circ}\cdot 5$ F. when breathing in an atmosphere of moderate temperature.* According to his calculations, when a person breathes 100 cubic centimetres of atmospheric air at the temperature of $60^{\circ}$ F., their bulk is increased to 107·87975 cubic centimetres when raised to the temperature of 99·5 F. in the lungs, since the expansive co-efficient of atmospheric air is 0·3665. As the expired air, however, contains 4·4 per cent. of carbonic acid gas, and as the expansive co-efficient of this last gas is 0·369087, the expansion of the expired air will differ slightly from what it would be were it composed of oxygen and nitrogen only, and will be 107·882197 cubic centimetres.†

It is difficult to obtain an accurate estimate of the quantity of watery vapour that escapes from the body along with the expired air. Were the inspired and expired air always fully saturated with moisture, and were their quantities, barometric pressure, and relative temperature accurately ascertained, the absolute and relative quantities of watery vapour which they contain could be calculated by certain algebraic formulæ. The atmospheric air which we breathe is sometimes saturated with moisture, more frequently the dew-point, or that at which the precipitation of the atmospheric moisture can occur, is considerably below the temperature of the air, and the number of thermometric degrees between the actual temperature of the air and the dew-point shows the degree of dryness in the air, or in other words how much it is below the point of saturation with moisture.‡ The loss of watery vapour by the lungs will evidently be regulated by the temperature of the inspired air, the quantity of watery vapour it holds in solution, the volume of air inspired, and the length of time it remains in the lungs. The lower the temperature of the inspired air, the less it approaches to the point of saturation with moisture, and the greater its volume, the greater will be the loss of watery vapour by the lungs. When the respirations are more rapid, and the sojourn of the air within the lungs is short, the same volume of expired air will probably contain less water in solution, than when its sojourn there is more prolonged, but the more frequent renewal of the air within the lungs will be more than sufficient to compensate for this.

The most correct and trust-worthy experiments to ascertain by the direct method the quantity of watery vapour in the expired air are those of Valentin and Brunner.* These experiments were performed upon seven males between the ages of $17\frac{1}{2}$ and 33 years, and the maximum of watery vapour exhaled was 13156·323 Troy grains in the 24 hours; the minimum 4511·374 grains, and the average 7819·222 grains. The quantity of watery vapour in the expired air within a given time varied in the same individual; and in one experiment it was increased after drinking. In these experiments the entire quantity of water in the expired air was ascertained, so that the actual quantity given off by the fluids of the body must have been less than this; and Valentin calculates that if a person breathes atmospheric air saturated with moisture, at the temperature of $60^{\circ}$ Fahr., and if the expired air be at the temperature of $99^{\circ}\cdot 5$ Fahr., and also saturated with moisture, about $\frac{5}{6}$ of the watery vapour contained in the expired air will be furnished by the fluids of the body.† We have seen that

* Moleschott (Holländische Beiträge zu den anatomischen und physiologischen Wissenschaften, band i. heft i. S. 86. Utrecht und Dusseldorf, 1846) has more lately made experiments on the temperature of the air in the back part of the mouth, and ascertained that in a range of temperature in the external air to the extent of $12^{\circ}\cdot 6$ F. that there was scarcely any difference in the temperature of the expired air. In 26 experiments, — three of which were upon women, — upon individuals chiefly from 19 to 43 years of age, he found the average temperature of the expired air to be nearly $98^{\circ}\cdot 6$ F. The longer or shorter time which the inspired air remains in the lungs will modify the results in such experiments.

† Opus cit.

‡ According to the calculations made by the late Professor Daniell (Elements of Meteorology, vol. ii. p. 316. London, 1845) from meteorological tables, kept for 17 years consecutively, the mean temperature of London is $49^{\circ}\cdot 54$ F., while the mean dew-point is $44^{\circ}\cdot 31$, giving $5^{\circ}\cdot 59$ upon the thermometric scale, and 827 upon the hygrometric scale, as the degree of dryness. The mean elastic force of this watery vapour is, he says, ·342 of an inch of mercury, and a cubic foot contains 3·806 grains of moisture. The greatest degree of dryness was $49^{\circ}$ F., or the least degree of moisture when the hygrometric scale was 235. According to Dalton's observations (Manchester Memoirs, 2nd series, vol. ii.) the medium of aqueous vapour in this climate (that of Manchester) may be estimated at ·30 of an inch of mercury due to the temperature of $44^{\circ}$ F. This vapour, he says, is increased by the temperature of $98^{\circ}$ in the lungs from ·30 to 1·74 inch of mercury, being an increase of 1·44 inch; but it will only be equal in weight to air of 1 inch of force, as the specific gravity of vapour is less than that of air in the proportion of 7 to 10. Valentin calculates (Opus cit. p. 533) that 100 cubic centimetres of dry air under a barometric pressure of 29·922 English inches, raised to the temperature of 99·5 F., and saturated with moisture, would be expanded to 106·488 cubic centimetres.

* Opus cit. p. 536. Lavoisier has given different estimates of the quantity of watery vapour in the expired air in his papers on respiration and transpiration in the Mémoires de l'Académie des Sciences. Hales, Menzies, and Abernethy, from experiments on themselves, and employing different kinds of apparatus, all more or less imperfectly suited for the purpose, have respectively estimated it at 9792 grs. or about 20 oz., 2880 grs. or about 6 oz., 4320 grs. or about 9 oz. Dalton and Thomson, from calculations based upon the relative quantities of watery vapour required to saturate the inspired and expired air, have estimated it respectively at 1·55 or nearly $1\frac{1}{2}$ lb. Troy or 8640 grs., and at 19 oz.

† Opus cit. p. 533. Vierordt (Physiologie des Athmens, &c. S. 155. 1845) calculates from the quantity

several of the calculations of the amount of the watery vapour exhaled from the lungs proceed on the supposition that the expired air is saturated with moisture, but this has not been substantiated by the only experiments made with the view of determining this point. In Moleschott's experiments, the amount of water held in solution varied. In five out of seven experiments the watery vapour in the expired air was appreciably less than what is sufficient to saturate air of the same temperature, while in one experiment it was saturated. On taking the average difference in the seven experiments performed, as much as possible under similar circumstances, between the actual quantity of moisture in the expired air, and in air of the same temperature saturated with moisture, he found that 2420 cub. cent. (147·620 Eng. cub. inches) of the expired air would require a quantity of watery vapour additional to that already existing in it equal to 10 millegrammes (·150 Eng. Troy grains) to saturate it. From these experiments he concludes "that in the greater number of instances the expired air in man is not saturated with watery vapour, but sometimes such a saturation occurs."* Magendie observed, in experiments on dogs, that the escape of an increased quantity of watery vapour from the mouth follows the injection of water into the veins, caused, as he supposes, by the transpiration from the lungs being considerably increased.†

Animal matters in quantities too minute to be subjected to analysis are also exhaled from the lungs, and escape along with the expired vapour. The condensed vapour from the lungs, when collected in a vessel, and kept for some days, putrefies, and emits an ammoniacal smell.‡ We are also often sensible of the escape of different substances, previously taken into the stomach, along with the expired air, by their smell; and the experiments of Nysten§, Magendie*, Tiedemann†, and others, prove that various organic and mineral substances, when injected into the veins, escape in part by exhalation from the lungs.

If the inspired air, during its sojourn in the lungs, becomes increased in bulk from an increase in temperature and an addition of watery vapour, it suffers a small diminution from the absorption of part of its constituent gases. The older experimenters observed a diminution in the air respired, but as they experimented with imperfect apparatus, and transmitted the expired air through water which would absorb part of the carbonic acid gas, little confidence is to be placed in their results.‡ There can be no doubt that a greater amount of oxygen disappears from the inspired air than what is sufficient for the formation of the quantity of carbonic acid gas in the expired air, and that there is a slight diminution in the bulk of the expired air from this cause; but we cannot speak so decidedly regarding any changes in the quantity of the nitrogen. Provençal and Humboldt§, in their experiments on the respiration of fishes, and Spallanzani ||, in his experiments on snails, observed an absorption of azote: while Jurine ¶ and Nysten**, in their experiments on the human species, and Berthollet††, Despretz‡‡, Dulong§§, and Martigny||||, in their experiments on warm-blooded animals, and Treviranus ¶¶ in his experiments on the cold-blooded animals, observed an exhalation of azote. Dr. W. F. Edwards***, in

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of air respired by himself in a state of rest, supposing the temperature of the expired air to be 98°·6 Fahr., and saturated with moisture, the temperature of the inspired air to be 57°·2 F., and containing only its average quantity of moisture, that the quantity of water in the expired air will amount in the 24 hours to 5555·880 Troy grains, of which, on an average, 4953·993 grains may be allowed for the loss of water from the inner surface of the lungs and air passages, and 601·887 grains for the quantity previously contained in the inspired air. As, however, the body is not at rest during a considerable part of the 24 hours, the loss of watery vapour must be greater than this.

* Holländische Beiträge zu den anatomischen und physiologischen Wissenschaften, band i. S. 96. 1846.

† Compendium of Physiology, translated by Milligan, p. 395. 1831.

‡ Valentin and Brunner (Opus cit. pp. 571, 572), in their experiments on the human species, detected the presence of a minute quantity of organic matter in the expired air. This was ascertained by the sulphuric acid, through which the expired air was made to pass, becoming red. Marchand (Journal für praktische Chemie, von Erdman und Marchand, band xxxiii. S. 129. 1844), in his experiments on frogs, also observed this.

§ Recherches de Physiologie, &c. p. 145.

* Opus cit.

† Zeitschrift für Physiologie, band v. 1835. This paper is translated in the British and Foreign Quarterly Review, vol. i. p. 241. Tiedemann, in this paper, has given an account of all the experiments previously performed on this point by others.

‡ Goodwyn (Opus cit. p. 51), Plaff (Nicholson's Journal of Natural Philosophy, vol. xii. p. 249. 1805), Dr. Alex. Henderson (Nicholson's Journal, vol. viii. p. 40), and Sir H. Davy (opus cit.), in their experiments on the human species, observed a diminution in variable proportions in the respired air; and Henderson, Plaff, and Davy, supposed that part of this diminution was caused by the absorption of nitrogen at the lungs.

§ Mém. de la Société d'Arcueil, tom. ii. p. 388. 1809.

|| Mémoire sur la Respiration, traduit par Senebier, pp. 162, 184, and 230. 1803. An absorption of azote was not uniformly observed by Spallanzani.

¶ Mémoire couronné en 1787, par la Société Royale de Médecine, as quoted by Nysten.

** Opus cit. p. 186.

†† Mém. de la Société d'Arcueil, tom. ii. p. 459.

‡‡ Annales de Chimie et de Physique, tom. xxvi. p. 337. 1824.

§§ Magendie's Journal de Physiologie, tom. iii. p. 45. 1823.

|||| Magendie's Journal, tom. x. p. 337. 1824.

¶¶ Zeitschrift für Physiologie, band iv. Treviranus says, "in some of my experiments there was more azote than carbonic acid exhaled, and this not only in the avertebrata, but also in the frog." p. 33.

*** De l'Influence des Agens Physiques sur la Vie, p. 420. Tableaux 63, 64, and 65. 1824. Dr. Edwards concludes from his experiments that there is both a constant exhalation and absorption of azote at the lungs, and that these two actions are sometimes equal, while at other times the one preponderates over the other.

his experiments upon warm-blooded animals and reptiles, found that in some cases the quantity of azote in the air respired was increased, in others diminished, while in others it remained unchanged; but these changes in the quantity of azote did not equal the difference between the amount of oxygen absorbed and of carbonic acid exhaled. Lavoisier and Seguin *, Allen and Pepys †, Valentin and Brunner ‡, and Dr. Thomson §, in their experiments on the respiration in the human species, detected no change upon the quantity of azote.‖ Boussingault ¶, by a series of comparative analyses of the aliments consumed, and of the excrements in a turtle-dove, arrived at the conclusion by this indirect method of research that azote was exhaled.

Marchand **, in his carefully-conducted experiments on frogs, detected a quantity of ammonia in the tube of his apparatus, containing the concentrated sulphuric acid, and concludes that nitrogen in this combination is exhaled from the lungs and skin.

From a review of all the experiments upon the nitrogen of the respired air, we perceive that though the evidence preponderates in favour of the exhalation of a small quantity of nitrogen from the lungs ††, yet that it is not sufficiently conclusive to justify us in stating that its operation is constant. It appears, however, from the evidence adduced, that the nitrogen in the expired air is at least frequently increased in quantity in ordinary respiration, but not to the extent of affecting materially the percentage of this gas in the respired air.* Valentin and Brunner, in their carefully conducted experiments, could detect no traces of hydrogen, carbonic oxide, or carburetted hydrogen, in the expired air.

By far the most important chemical change the atmospheric air undergoes during its sojourn in the lungs, is a diminution in the quantity of its oxygen and an increase of its carbonic acid gas; and it may be safely affirmed that all the other changes in the respired air are of trivial importance in the function of respiration, when compared with this. There can be no doubt that the conclusion drawn by Allen and Pepys from their experiments, that the amount of oxygen which disappears from the inspired air is exactly equal to the quantity required to form the carbonic acid that appears in the expired air, is incorrect; for all the latest and most accurate experiments have confirmed the general accuracy of the results obtained by Lavoisier and Davy on this point, and have satisfactorily determined that a larger quantity of oxygen disappears from the inspired air than what is sufficient to form the carbonic acid gas present in the expired air.

*Percentage and absolute quantity of carbonic acid gas in the expired air.* — The results of the earlier experimenters on this point are of so little value that we need not refer to them. The following results have been obtained by some of the later experimenters: —

QUANTITY OF CARBONIC ACID GAS IN THE 100 PARTS OF THE EXPIRED AIR ESTIMATED BY VOLUME.

| | Average. | Max. | Min. | Difference between Maximum and Minimum. |
|---|---|---|---|---|
| Prout | 3·45 | 4·10 | 3·30 | ·80 † |
| Coathupe | 4·02 | 7·98 | 1·91 | 6·07 ‡ |
| Brunner & Valentin | 4·380 | 5·495 | 3·299 | 2·196 § |
| Vierordt | 4·334 | 6·220 | 3·358 | 2·86 ‖ |
| Thomson | 4·16 | 7·16 | 1·71 | 5·45 ¶ |

* Mém. de l'Académie Royale for 1789, p. 574.

† Opus cit.

‡ Opus cit.

§ Animal Chemistry, p. 612. 1843. Dr. Thomson says, in experimenting upon animals placed in vessels in which the air was renewed during the experiment, no diminution of the volume of air took place, but the case was very different when the animal was obliged to breathe confined air. Nysten (Opus cit. p. 230) observed an evolution of azote in the human species, both in a state of health and disease, when the same air was breathed several times. Marchand, on the other hand (Journal für praktische Chemie, band xxxiii. S. 166), from his experiments on frogs placed in close vessels, concludes that it is exceedingly probable, if not certain, that, under this condition, these animals absorb part of the azote of the atmospheric air.

‖ Vierordt remarks upon Valentin and Brunner's experiments, and the same observation applies to the others on the human species, that the evolution of a minute quantity of nitrogen, not readily detected during the short time each of these experiments was carried on, might amount to a notable quantity in the 24 hours.

¶ Annales de Chimie et de Physique, tom. xi. p. 433. 1844. In taking the mean of the result of his experiments, he found a turtle-dove, weighing 2885·971 English Troy grains, evolved in 24 hours from the lungs 288·597 grains of carbonic acid gas, and 2·469 grs. of azote, or in volume 576·155 English cubic inches of carbonic acid and 7·689 cubic inches of azote,—a considerably smaller quantity than was obtained by Dulong and Despretz in their experiments by the direct method. This quantity of azote, according to Boussingault, constitutes the one-third of the whole of this substance which entered into the composition of the aliment of the pigeon.

** Opus cit.

†† It must, however, be remembered that in the great majority and in the most trust-worthy of these experiments in favour of the increase of the nitrogen, the exhalations from the skin were mixed with those from the lungs.

* Even supposing the nitrogen of the respired air to remain unaltered in quantity, yet as the quantity of oxygen absorbed is somewhat greater than what is necessary to form the carbonic acid exhaled along with the expired air, the percentage of the nitrogen in the inspired air will be slightly greater than in the expired air when estimated by volume.

† Thomson's Annals of Philosophy, vol. ii. p. 333. 1813. In some subsequent experiments by Prout (same work, vol. iv. p. 331) the range in the quantity of carbonic acid gas in the expired air was between 2·80 and 4·70, the minimum number occurring once only, and while he was sleepy. Prout's experiments were performed upon himself, and at every hour of the day and night.

‡ London, Edinburgh, and Dublin Philosophical Magazine, vol. xiv. p. 401. 1839. These experi-

The results obtained by Brunner and Valentin, and by Vierordt, appear especially trustworthy; and though the number of experiments is too small to enable us to deduce averages with any confidence, yet we may in the meantime consider that, in an adult male of middle age, the average quantity of carbonic acid in the expired air is about 4·35 per cent.* The quantity of carbonic acid gas in the expired air is not uniform in the same individual, but varies repeatedly, even in the course of the twenty-four hours, and these variations are determined by certain conditions of the body and of the surrounding media.

*Period of the day.* — Dr. Prout believed that he had discovered that the quantity of carbonic acid formed during respiration is always greater at one and the same period of the day than at any other; that this maximum occurs between 10 A.M. and 2 P.M., or generally between 11 A.M. and 1 P.M.; and that the minimum commences about $8^{h}$ 30′ P.M., and continues nearly uniform till about $3^{h}$ 30′ A.M. The beginning and end of the period of minimum evolution of carbonic acid he believed to be connected with the beginning and end of twilight, and he adduces some experiments in favour of this opinion. In these experiments Prout attended only to the percentage of the carbonic acid in the expired air, and took no means to ascertain the volume of air passing through the lungs at the time, — an omission which seriously diminishes their value.† Prout's results do not accord with the previous experiments of Brande ‡, nor with the subsequent experiments of Coathupe* and Vierordt. † It would appear, therefore, that the variations in the quantity of carbonic acid in the course of the day do not occur at uniform periods, independent of other circumstances, as Prout supposed. It is, however, proved by the experiments of Scharling ‡ upon the human species, by Boussingault § upon the turtle dove, and by Marchand || upon frogs, that the absolute amount of carbonic acid exhaled is very considerably less during the night than during the day. Scharling gives in the following table the relative proportion of the carbon exhaled during the day and night in six individuals upon whom he experimented: —

| | Night. | Day. |
|---|---|---|
| 1. Scharling - - | 1 | 1·237 |
| 2. Thomson - - | 1 | 1·235 |
| 3. A Soldier - - | 1 | 1·420 |
| 4. An adult Female - | 1 | 1·240 |
| 5. A Boy - - - | 1 | 1·266 |
| 6. A Girl - - - | 1 | 1·225 |

The average proportion is 1 during the night to 1·237 during the day, or, in other words, nearly a fourth part more carbonic acid gas is evolved during the day than during the night.¶ How much of the diminished evolution of carbonic acid during the night is dependent upon the languor and drowsiness incident to that period, and how much upon the absence of the sun's rays and other causes, it is at present impossible to determine. It appears that this diminished evolution of carbonic acid during the night does not require the occurrence of sleep, though no doubt it is increased by sleep.

*Digestion.* — Seguin and Lavoisier **, in their experiments upon Seguin found that when he was in a state of repose and fasting he vitiated only 1210 cubic inches of oxygen gas in an hour, while, during digestion, this was raised to between 1800 and 1900 cubic

ments were 124 in number, and performed upon himself at almost every hour of the day between 8 A.M. and midnight. The difference between the maximum and minimum percentage is great in Coathupe's experiments; but this was only found in single cases.

§ Opus cit. p. 546. These experiments were 34 in number, and performed upon three adult males between 33 and 53 years of age.

|| Article Respiration in Wagner's Handwörterbuch, p. 853. Vierordt's experiments were performed upon himself, were nearly 600 in number, were continued over a period of nearly 15 months, and were chiefly made between 9 A.M. and 7 P.M. Vierordt, in his Physiologie des Athmens, has given in a tabular form the results obtained in 578 experiments, p. 21—65.

¶ Animal Chemistry, p. 614. 1843. These experiments were made on 10 males and 2 females, and between 11 and 12 o'clock A.M.

* Dalton (Opus cit. p. 25), Dumas (Essai de Statique Chimique des Etres Organisés, 3me edit., p. 87. 1844), and Gay Lussac (Annales de Chimie et de Physique, tom. xi. p. 14. 1844), estimate the average carbonic acid in the expired air at 4 per cent. Apjohn (Dublin Hospital Reports, vol. v. 1830), and Macgregor (Transactions of British Scientific Association for 1840, p. 87), estimate it at 3·6 and 3·5 per cent. The estimate of Allen and Pepys (Opus cit.), and Dr. Fyfe (Dissert. Chemico-Physiol. Inaug. de Copia Acidi Carbonici e Pulmonibus inter respirandum evoluti. Edinburgh, 1814), making the average quantity 8· to 8·5 per cent., is undoubtedly considerably too high; and they were led into this error by the impediment to the free respiration occasioned by the imperfect apparatus employed.

† Thomson's Annals of Philosophy, vols. ii. and iv.

‡ Nicholson's Journal, vol. xi. p. 82.

* Opus cit.

† Physiologie des Athmens, &c., S. 66.

‡ Annalen der Chemie und Pharmacie, band xlv. s. 214. 1843. Translated in Annales de Chimie et de Physique, tom. viii. p. 478. 1843.

§ Annales de Chim. et de Phys., tom. xi. p. 445. 1844. Boussingault calculates from his experiments that, supposing the entire day to be divided into 12 hours of sleep, and 12 hours of waking, the quantity of carbon consumed in respiration by the turtle-dove during the day and night would be as follows: —

| | |
|---|---|
| Carbon consumed in the day (English Troy grains per hour) .................... | 3·981 |
| Carbon consumed in the night (ditto) .. | 2·500 |

|| Journal für praktische Chemie, von Erdman und Marchand, band xxxiii. S. 148. 1844.

¶ Annalen der Chemie und Pharmacie, band xlv. S. 236.

** Mémoire de l'Académie Royale for 1789, p. 574, 575. Jurine (Encyclopédie Méthodique, Médecine, article Air, tom. i. p. 497. 1787) has also maintained that a greater quantity of air is vitiated during digestion.

inches. Spallanzani * observed that snails, after a redundant repast, exhaled considerably more carbonic acid gas than when fasting. Similar observations have been made upon insects by Sorg † and Newport ‡, upon the Mammalia by Zimmermann §, and upon the human species by Scharling ||, Valentin ¶, and Vierordt. The most complete experiments on this point are those of Vierordt, performed on himself, the results of which are contained in the following tables. His dinner lasted from 30 minutes past 12 to 1 o'clock : —

| Hours. | Pulse per minute. | Respirations per minute. | Volume of an Expiration. (In English cubic inches.) | Expired in one minute. Air. (In English cubic inches.) | Expired in one minute. Carbonic acid gas. (In English cubic inches.) | Per centage of carbonic acid in the expired air. |
|---|---|---|---|---|---|---|
| 12 | 66·5 | 11·55 | 31·43 | 362·64 | 15·77 | 4·32 |
| 2 | 82·3 | 12·77 | 32·26 | 412·17 | 18·22 | 4·37 |
| Difference | 15·8 | 1·22 | ·83 | 49·53 | 2.45 | ·05 |

To ascertain that this increase in the quantity of carbonic acid evolved from the lungs was really dependent upon digestion, and not upon any other cause, the experiment was repeated at the same period of the day when he had not dined, and had eaten nothing since his breakfast at 7 o'clock, and the following results were obtained : —

| Hours. | Pulse per minute. | Respirations per minute. | Volume of an Expiration. (In English cubic inches.) | Expired in one minute. Air. (In English cubic inches.) | Expired in one minute. Carbonic acid gas. (In English cubic inches.) | Per centage of carbonic acid in the expired air. |
|---|---|---|---|---|---|---|
| 12 | 63 | 10 | 33·25 | 332·58 | 16·49 | 4·69 |
| 1 | 64 | 9 | 32·16 | 289·44 | 14·75 | 5·09 |
| 2 | 62·5 | 9½ | 35·08 | 334·35 | 15·75 | 4·73 ** |

* Mémoires sur la Respiration, p. 217—223.

† Disquisitio Physiologica circa Respirationem Insectorum et Vermium. 1805.

‡ London Phil. Trans. for 1836 and 1837.

§ The result of Zimmermann's experiments is given on Vierordt's authority in Wagner's Handwörterbuch, band ii. S. 884.

|| Opus cit. In Scharling's experiments the total quantity of carbonic acid exhaled from the body during a given time was determined, and they are, therefore, not liable to the errors of those experiments where the percentage only was ascertained.

¶ Opus cit. p. 566. Valentin states that an hour after he had taken a meal of bread and butter, the quantity of carbonic acid given off by the lungs was raised from 616·085 to 627·505 English Troy grains per hour, while after a fast of 16 hours it fell to 579·972 grains per hour.

** Physiologie des Athmens, &c. S. 91 und 94.

Notwithstanding, therefore, that Prout failed to observe any decided increase in the quantity of carbonic acid gas thrown off by the lungs during digestion, and that Mr. Coathupe maintains from his experiments that the carbonic acid in the expired air increases with increased abstinence from food, and that its *maximum* quantity is *before breakfast* and *immediately before dinner* *, we must consider the evidence detailed above perfectly conclusive in proving that the quantity of carbonic acid evolved in respiration is considerably increased after a full meal.

*Fasting.* — In describing the effects of digestion upon the quantity of carbonic acid evolved from the lungs, we were led to refer to the manner in which the opposite condition of the body, or that of fasting, operates. That fasting diminishes the quantity of carbonic acid in the expired air is not only proved by the facts already mentioned, but also by the experiments of Scharling upon the human species, of Boussingault upon the turtle dove, and of Marchand upon frogs. The two last experimenters found that in very prolonged fasting the quantity of carbonic acid was greatly diminished.

*Alcohol.* — Dr. Prout states that alcohol, and all liquors containing it which he had tried, have the remarkable property of diminishing the quantity of carbonic acid gas in the expired air much more than any thing else he had made the subject of experiment, and its effects were most remarkable when taken on an empty stomach. Vierordt mentions, in confirmation of Prout's observations on this point, that in four experiments, after having taken from one half to a bottle of wine, the percentage of carbonic acid had fallen, a quarter of an hour after this, from 4·54 to 4·01, and it continued to exercise this effect from one to two hours.†

The quantities of atmospheric air and carbonic acid are calculated in the original tables in cubic centimetres. In reducing these to English cubic inches, one cubic centimetre has been considered to be equal to ·06102523 of an English cubic inch.

* London, Edinburgh, and Dublin Philos. Magaz. vol. xiv. p. 409 and 413. The number of meals and the times at which they were taken explain the results obtained by Mr. Coathupe. He lunched at 1 o'clock P. M., and at 2 P. M. the average percentage of carbonic acid gas was raised from 3·92 to 4·17, and thus so far in accordance with the experiments mentioned above. At 5½ P.M. he took a good dinner, with a pint of wine. Now, as alcohol diminishes the quantity of carbonic acid evolved from the lungs, this might have counteracted the effects of digestion for a time. It must also be remembered that Mr. Coathupe ascertained only the percentage, not the absolute quantity of carbonic acid evolved; and Vierordt ascertained by experiment (Physiologie des Athmens, &c. S. 93) that when he drank wine at dinner the percentage of the carbonic acid in the expired air was diminished; and that, though its absolute quantity was increased, this was not nearly to the same extent as when no wine was taken. Were experimenters always to detail minutely the circumstances under which they performed their experiments, it would frequently be found, as in the present case, that results, apparently most discordant, are not so in reality.

† Wagner's Handwörterbuch, band ii. S. 884; and Physiol. des Athmens, &c. S. 97.

A strong infusion of tea has, according to Prout, an effect similar to alcohol.

According to Dr. Fyfe, when a person has taken mercury or nitric acid for some time, the quantity of carbonic acid is diminished.

*Conditions of the mind.*— Prout found that anxiety and the depressing passions diminish the percentage of carbonic acid in the expired air ; and Vierordt, on two occasions, observed this effect, for a short time at least, from mental emotions, both of a joyful and of an opposite nature. Scharling remarked that in those persons who felt very anxious on being enclosed in the box used by him in his experiments, the evolution of carbonic acid gas from the body was much diminished.

*Exercise.*— Prout states that moderate exercise, as walking, seems always at first to increase the evolution of carbonic acid, but when continued it ceases to produce this effect, and when carried the length of fatigue the quantity is diminished : that violent exercise appears to lessen the quantity from the first, or if any increase occurs, this is trifling and transitory ; and that, after violent exercise, the quantity is much lessened. In Prout's mode of experimenting, the percentage of carbonic acid having been alone ascertained, we have no certain means of judging of the changes in the *absolute* quantity of carbonic acid evolved, as the increase in the number of respirations and in the bulk of the air respired, occasioned by exercise, was not taken into account. In the experiments of Seguin and Lavoisier already referred to, it was found that Seguin, when fasting and at rest, vitiated in the hour 1210 cubic inches of oxygen gas : by an amount of exercise equal to raising 15 lbs. to a height of 613 feet, this was increased to 3200 while still fasting, and to 4600 cubic inches, while digesting food. In Scharling's experiments, where the absolute quantity of carbonic acid gas evolved from the whole body in a given time was ascertained, the quantity of carbonic acid was increased during exercise. Vierordt ascertained that during the increased respiratory movements occasioned by moderate exercise, that on an average there was an increase per minute of 18·978 English cubic inches in the expired air, containing an increase of 1·197 cubic inch of carbonic acid gas, giving, however, an increase of carbonic acid gas in the expired air of only 0·140 per cent. There can, therefore, be no doubt that the evolution of carbonic acid gas from the lungs can be considerably increased by exercise.*

*Temperature.*— The effects of low temperatures upon the respiratory process, as ascertained by Spallanzani and Treviranus upon snails and insects, by Marchand upon frogs, and by different observers upon the hybernating warm-blooded animals, are not applicable to the human species, since the reduction of the temperature to a certain extent induces in these animals a lethargic condition, well known under the term hybernation, altogether different from its effects upon man and the other warm-blooded animals. Seguin and Lavoisier state that in their experiments, Seguin, in a temperature of 82° Fahr., fasting and at rest, consumed, in the space of an hour, 1210 French cubic inches of oxygen ; while in a temperature of 57° Fahr., he consumed in the same time 1344 cubic inches.* Crawford †, in experiments upon guinea-pigs, ascertained that these animals, in a given time, deteriorate a greater quantity of air in a cold than in a warm medium. The most perfect experiments on this point, at least on the human species, are those of Vierordt.‡ He ascertained, by numerous trials upon himself, the effects of temperature from 37°·4 to 75°·2 Fahr. From a table, showing the results obtained, both upon the respiration and the pulse, at each degree of the centigrade thermometer within the limits mentioned, he has constructed the following shorter table, where the first table is arranged in two divisions,—the one containing the average of all the lower, and the other the average of all the higher temperatures. In the following table the measures of the expired air and carbonic acid have been reduced to English cubic inches.

| | Average of the lower temperature, 47°·24 F. | Average of the higher temperature, 66°·92 F. | Difference between the higher and lower temp. |
|---|---|---|---|
| Pulse per minute | 72·93 | 71·29 | 1·64 |
| Respirations per minute | 12·16 | 11·57 | 0·59 |
| Volume of an expiration in cubic inches | 33·44 | 31·76 | 1·68 |
| Expired air per minute | 406·99 | 366·97 | 40·02 |
| ——— carbonic acid per minute | 18·25 | 15·72 | 2·53 |
| Carbonic acid gas in the 100 parts of the expired air - - - - | 4·48 | 4·28 | 0·20 |
| Barometer, in English inches - - - | 29·719 | 29·647 | |

The experiments of Letellier § on warm-blooded animals agree in their results with

* G. R. Treviranus (Zeitschrift für Physiologie, vierter band, S. 29. 1831) and Newport (opera cit.) in their experiments upon insects, observed a marked increase in the exhalation of carbonic acid gas in these animals during active voluntary movements.

* Mémoires de l'Académie Royale for 1789.

† Experiments and Observations on Animal Heat, p. 311—315. 2nd edit. 1788.

‡ Wagner's Handwörterbuch, band ii. S. 878, 879, und 880. Physiologie des Athmens, S. 73—82.

§ Comptes Rendus, tom. xx. p. 795. 1845. Annales de Chimie et de Phys. tom. xiii. p. 478. 1845. Letellier has thrown the results of his experiments into the following table. He does not state whether he measured the temperature by Reaumur, or the

those of Vierordt. He found that the quantity of carbonic acid gas evolved from the body at the freezing point, was double of that at an elevated temperature, in the two mice and guinea-pig, and a little more in the canary and pigeon. There can, therefore, be no doubt that more carbonic acid gas is evolved from the body in a cold, than in a warm temperature.

*Effect of the seasons.*—Dr. W. F. Edwards* ascertained, by several well-devised experiments, that birds placed under exactly the same circumstances, and with the surrounding air of the same temperature, consumed more oxygen in winter than in summer, and this appears to be connected with that change in the constitution of the warm-blooded animals in the colder regions of the earth, by which they are enabled to generate more caloric in winter than in summer.

*Barometric pressure.*—Legallois found that when warm-blooded animals breathed air in a vessel under an atmospheric pressure reduced to 30 centimetres (11·811 English inches), the quantity of oxygen gas consumed was diminished.† Prout, on the other hand, informs us, that, in every instance in his experiments, any remarkable increase in the percentage of carbonic acid in the expired air was accompanied by a sinking barometer.‡ Vierordt tested the effects of a range of the barometric scale between 330‴ (29·309 English inches) and 340‴ (30·197 English inches), and has thrown the results into a tabular form. The measure of the expired air was calculated under the ordinary pressure of 336‴ (29·841 English inches). He found that a rise of 5‴·67, (the mean between the experiments at the lower and those at the higher pressures,) produced the following effects:—

It increased the pulsations in one minute 1·3
„ respirations ............ 0·74
„ expired air (cubic in.) 35·746

As, however, the percentage of the carbonic acid in the expired air was greater at the lower than at the higher pressures, in the proportion of 4·450 to 4·141, the difference between the absolute quantity of that gas in the expired air at the higher exceeds so little that at the lower pressures, that it may be reckoned as nil.*

*Age, sex, and constitution of body.*—The quantity of carbonic acid evolved from the body is not only influenced by the ingesta and the varying conditions of the surrounding media, but also by the age, sex, and constitution of the body. The only important researches into the effects which these last conditions of the body have upon the evolution of the carbonic acid, are those of Andral and Gavarret†, and Scharling‡; and though they are far from having exhausted the subject, they possess the merit of having been carefully and accurately conducted, and of being carried on in the right direction. Andral and Gavarret availed themselves in their experiments of the apparatus suggested by Dumas and Boussingault. Part of this apparatus consists of a mask, which can be fitted air-tight to the face, and having a tube on each side, on a level with the commissures of the lips, provided with valves permitting the external air to pass in, but preventing its passage outwards. In front of the mouth there is a large aperture for conducting outwards the expired air; and to this a tube can be attached for conducting it into the receivers and other parts of the apparatus prepared for ascertaining the quantity of carbonic acid gas. A person can breathe through this apparatus without constraint; and the experiments were all performed between one and two o'clock P.M., each lasting from eight to thirteen minutes, and the individuals experimented upon were placed, as far as possible, under the same conditions with regard to food, muscular exertion, and state of the mind. They experimented upon sixty-two individuals of different ages, and of both sexes. They restricted their valuation of the quantity of carbonic

Centigrade scale, but we believe that it was the latter.

| | Surrounding Temperature. | | |
|---|---|---|---|
| | From 15° to 20° | From 30° to 40° | At the freezing point. |
| | grammes | grammes | grammes |
| For a Canary | 0·250 | 0·129 | 0·325 |
| For a Pigeon | 0·684 | 0·366 | 0·974 |
| For two Mice | 0·498 | 0·268 | 0·531 |
| For a Guinea Pig | 2·080 | 1·453 | 3·006 |

* De l'Influence des Agens Physiques sur la Vie, chapitre vi.

† Annales de Chimie et de Physique, tom. iv. p. 113. 1817.

‡ Thomson's Annals of Philosophy, vol. iv. p. 335.

* Dr. Hutchinson (Medico-Chirurgical Transactions of London, vol. xxix. p. 228) has given some experiments upon the effects of an increased barometric pressure upon the frequency of the respiratory movements. These were made upon six persons before and after descending a mine, 1488 feet deep, where the barometric pressure was 1·54 inch more than at the level of the sea. As there was a difference of 10 degrees in the temperature at the top and bottom of the mine, this ought to be taken into account in judging of the results. The pulse was increased at the bottom of the mine on an average 1·3 per minute, and the respirations 2·4 per minute. The accounts given by travellers of the effects upon their respiration in elevated regions are so discordant that we can deduce no very satisfactory conclusions from them.

† Annales de Chim. et de Phys. tom. viii. p. 129. 1843.

‡ Annalen der Chemie und Pharmacie, band xlv. S. 214. 1843, translated in Annales de Chim. et de Phys. tom. viii. p. 478. 1843. In Scharling's experiments, as in those of Andral and Gavarret, the absolute quantity and not the percentage of carbonic acid gas in the expired air was determined. In Scharling's first experiments, the carbonic acid gas given off at the external surface of the body was mixed with that given off by the lungs.

acid evolved from the lungs to one hour, being perfectly aware of the fallacy of attempting to estimate from experiments so limited as to time, the quantity given off in the twenty-four hours. Scharling conducted his experiments in a different manner. He enclosed the individuals experimented on in a box, perfectly air-tight, and so large as to permit a person to work, read, or even sleep, during the experiment. Tubes were fixed in the box, to admit the external air freely, and to conduct the expired air into an apparatus fitted for determining the amount of the carbonic acid. The individuals experimented on remained in the box generally for an hour at a time, sometimes an hour and a half, but also often from thirty to forty minutes only; and precautions were taken to keep up a free circulation of atmospheric air through the box during the whole of the experiment. His experiments were performed upon six persons, of different ages and of both sexes.

Andral and Gavarret have drawn the following conclusions from their experiments:

1. The quantity of carbonic acid gas exhaled from the lungs, in a given time, varies according to the age, the sex, and the constitution of individuals; and that, independently of the weight of the body. 2. At all periods of life extending from 8 years (the earliest age subjected to experiments) up to the most advanced old age, the quantity of carbonic acid evolved from the lungs differs in the two sexes, but, *cæteris paribus*, the male exhales a considerably larger quantity than the female. This difference is most marked between 16 and 40 years of age, during which period the male generally evolves nearly twice as much as the female. 3. In the male, the quantity of carbonic acid exhaled goes on continually increasing from 8 to 30 years of age, and becomes suddenly very great at the age of puberty. After 30 years of age it begins to decrease, and this so much the more decidedly as the person approaches extreme old age, at which period it may be reduced to the quantity evolved at 10 years of age. 4. In the female also, the evolution of carbonic acid increases from infancy up to puberty; but at this period, contrary to what takes place in the male, it remains stationary, so long as the menstrual secretion continues natural. At the time the menses cease, the evolution of carbonic acid gas from the lungs undergoes a marked augmentation; but after a while it begins to decrease, as in the male, and proportionally as she advances towards old age. 5. In the female, during gestation, the exhalation of carbonic acid from the lungs equals the quantity exhaled at the period of the cessation of the menses. 6. In both sexes, and at all ages, the quantity of carbonic acid is so much the greater, as the constitution is stronger and the muscular force more developed.

The most important of the data upon which the above inferences are founded are as follows:—

In the male child, in his progress upwards from his 8th to his 15th years, the quantity of carbon given off by the lungs was raised, on an average, from 5 grammes (77·165 Troy grains) to 8·7 grammes (134·267 Troy grains) per hour; while in the female at the same age it was on an average 1 gramme (15·433 Troy grains) less per hour. In the male at 16 years of age, or soon after puberty, it suddenly increased to 157·416 Troy grains, on an average, per hour; and from this period up to the age of 20 and 25 it gradually increased, on an average, to 172·849 and 191·369 Troy grains per hour. At this point it remained nearly stationary until about 40 years of age, when it began to undergo a slight diminution, but not to any great extent until 60 years of age. Adult females, who menstruated regularly, lost, on an average, 98·771 grains only of carbon, by the lungs, in an hour,—a quantity not greater than that lost by girls. Take the average loss of carbon, by the lungs, in the male at 174·392 grains between the ages of 15 and 20 years, it is, on an average, 155·873 grains between 40 and 60 years; and 141·953 grains between 60 and 80 years. In the female, at the period of the cessation of the menses, the loss of carbon is suddenly elevated from an average of 98·771 to 129·637 grains per hour; and a similar elevation, and nearly to the same extent, was observed in four females during pregnancy. In females between 50 and 60 years of age, the loss was 112·660 grains, and between 60 and 80 it was, on an average, 104·944 grains in an hour. In one female of 82 years, it was 92·595 grains, and in a male of 102, but remarkably hale for his years, it was 91·590 grains. In a male, aged 26, and remarkable for his muscular development, the loss was as high as 217·105 grains, while in another male, aged 45, of moderate height, but extremely feeble muscular development, it amounted on an average only to 132·723 grains an hour.* Scharling, after allowing seven hours for sleep to an adult, and nine for a child, calculates, from his experiments on six individuals, the amount of the loss of carbon from the body as follows:—

| | Age—years | Weight of body in Troy lbs. | Quantity of carbon exhaled in grains. | |
|---|---|---|---|---|
| | | | In 24 hours. | In 1 hour. |
| Male - - | 16 | 154·73 | 3453·90 | 143·91 |
| —— - - | 28 | 219·70 | 3699·50 | 154·14 |
| —— - - | 35 | 175·49 | 3386·77 | 141·11 |
| Average of men | 26½ | 183·30 | 3513·39 | 146·39 |
| Boy - - | 9¾ | 58·96 | 2054·53 | 85·60 |
| Girl - - | 10 | 61·64 | 1929·89 | 80·41 |
| Aver. of children | 9⅞ | 60·30 | 1992·21 | 83·10 |
| Woman - | 19 | 149·41 | 2540·88 | 105·87 † |

* Brunner and Valentin (opus cit. p. 567), from

In these experiments of Scharling the evolution of carbonic acid by the skin was included, with that evolved through the mouth and nostrils; and the quantity is calculated for the twenty-four hours. But in some subsequent experiments, by uniting the use of the mask used by Andral and Gavarret with the box, he has been enabled to ascertain the relative amount of the loss by these two different channels in an hour. In other respects, he has endeavoured to assimilate his experiments, in regard to the hour of the day, &c., to those of Andral and Gavarret, and has given the following comparative view of the results: —

| | Total quantity of carbon from the whole body in Troy grains. | Carbon from general surface of body. | Carbon expired through the mouth and nostrils in Troy grains. | |
|---|---|---|---|---|
| | | | Scharling. | Andral and Gavarret. |
| 1. Male aged 28 years | 181·183 | 5·756 | 175·426 | 191·369 |
| 2. — — 16 — | 169·763 | 2·793 | 166·969 | 157·416 |
| 3. Boy — 9¾ — | 101·086 | 1·913 | 99·172 | 91·054* |
| 4. Young Woman 19 — | 128·340 | 4·197 | 124·143 | 108·031 |
| 5. Girl - - 10 — | 95·622 | 1·913 | 93·709 | 92·598 † |

*Influence of the respiratory movements upon the evolution of carbonic acid from the lungs.*— This point has been particularly examined by Vierordt in 171 experiments upon himself, and he has ascertained that the frequency, extent, and duration of the respiratory movements have a marked effect, not only upon the relative proportion of the carbonic acid gas in the expired air, but also upon the absolute quantity evolved from the lungs in a given time.‡ We shall afterwards find, when we come to describe the theory of respiration, that the results obtained by Vierordt are of considerable importance in a theoretical point of view.

*Frequency of the respiratory movements.*— When the number of respirations is less than usual, the percentage of the carbonic acid in the expired air is increased, while its absolute quantity is diminished; on the other hand, when the respirations are more frequent than usual, the percentage of carbonic acid in the expired air is diminished, while its absolute quantity is increased. Vierordt endeavours to point out that the diminution in the percentage of the carbonic acid gas in the expired air when the respirations are more frequent, probably bears a certain proportion to their frequency or length per minute, supposing their bulk to be the same. The operation of this law, according to Vierordt, may be illustrated as follows. Let us take the average number of respirations in a state of rest as 12, and suppose these to be doubled or increased to 24, the relative percentage of carbonic acid will be diminished by 0·8; if the number of respirations be again doubled, or increased to 48, the carbonic acid will suffer a still further diminution of 0·4 per cent.; and if the respiration be again doubled, and increased to 96 per minute, the carbonic acid will suffer a farther reduction of 0·2 per cent. On the other hand, if the number of respirations be less than 12 (here taken as the normal number of respirations by Vierordt) by one half or reduced to 6 in the minute, the relative percentage of carbonic acid will be increased above what it is in the normal frequency by 1·6. If the percentage of carbonic acid in the expired air be 4·1, when the respirations are 12 in the minute, it will be 5·7 per cent. when the respirations are 6, and 2·7 per cent. when they are 96 in the minute. Proceeding upon the existence of this law, he supposes that if the respirations were increased from 96 to twice that number, or 192, the percentage of the expired air would suffer a farther reduction of only 0·1 per cent.; in other words, it would be reduced from 2·7 to 2·6 per cent. This last ratio, viz. 2·6, he believes to be the smallest percentage of carbonic acid gas that the expired air can present. If Vierordt be correct in supposing that the percentage of carbonic acid in the expired air has a fixed arithmetical proportion to the frequency or length of the respiratory movements, we could, after determining the normal number of respirations, the bulk of air expired, and the percentage of carbonic acid

six experiments on themselves, calculate that 172·664 Troy grains of carbon were thrown off from the lungs in an hour.

† This table is given in the form into which it has been thrown by Hannover (De Quantitate relativa et absoluta Acidi Carbonici ab homine sano et ægroto exhalati, p. 17. 1845) and the kilogrammes and grammes in the original table have been reduced to Troy pounds and Troy grains.

* As the boy upon whom Scharling experimented was of slender form, he has taken the average of the results of Andral and Gavarret upon two boys of 10 and 8 years as the standard of comparison in this case.

† Wöhler and Liebig's Annalen der Chemie und Pharmacie, band lvii. S. 1. 1846. The male adult and the boy were naked during the experiment.

‡ Physiologie des Athmens, vierter abschnitt, S. 102—149.

gas, when the body is in a state of rest, be able to determine both the relative and the absolute quantity of carbonic acid gas in the expired air from the number of respirations alone, when these are either increased above, or diminished below the normal number, provided the bulk of each respiration continues equal. He has constructed the following table to illustrate the variations in the absolute quantity of carbonic acid gas occasioned by alterations in the frequency of the respiratory movements. The normal number of respirations is supposed to be 12, the average bulk of each respiration to be 500 cubic centimetres (30·5 English cubic inches), and the percentage of carbonic acid to be 4·1.

| Number of respirations in a minute. | Percentage of carbonic acid in the expired air. | Volume of the expired air in a minute. | Volume of carbonic acid gas in the expired air in a minute. | Volume of carbonic acid gas in each expiration. |
|---|---|---|---|---|
| | | Measured in English cubic inches at a temperature of 98°·6 F., and under a barometric pressure of 29·841 English inches. | | |
| 6 | 5·7 | 183·000 | 10·431 | 1·738 |
| 12 | 4·1 | 366·000 | 15·006 | 1·250 |
| 24 | 3·3 | 732·000 | 24·156 | 1·006 |
| 48 | 2·9 | 1464·000 | 42·456 | 0·884 |
| 96 | 2·7 | 2928·000 | 79·056 | 0·823 |

*Bulk of the air expired.*— The quantity of air thrown out of the lungs at each expiration has also an influence upon the percentage and absolute quantity of carbonic acid gas in the expired air. Vierordt, in six experiments, found that while the average of carbonic acid gas in the expired air in a normal expiration in a state of rest was 4·78 per cent., in the deepest expiration he could make, it was 4·05 per cent.

*The stoppage of the respiratory movements for a time* has also a marked effect upon the quantity of carbonic acid in the expired air. Vierordt has made four series of experiments upon himself to ascertain the extent of this influence upon the quantity of carbonic acid evolved from the lungs. In the first series he shut his mouth and held his nose from 20 to 60 seconds (the longest period he could continue the experiment), and then made the deepest possible expiration. In the second series he made the deepest inspiration possible, then suspended the respiratory movement for a longer or shorter time, at the termination of which he made the deepest expiration. This experiment he was able to prolong to 70, 90, and even 100 seconds. In the third series he made an ordinary inspiration before suspending the respiratory movements, and after this suspension had continued for different periods up to 30 seconds, he made an ordinary expiration. The fourth series of experiments was to ascertain the period of time after the stoppage of the respiratory movements when the percentage of carbonic acid gas becomes uniform in the different parts of the lungs and air passages, and this he found took place after 40 seconds. He has arranged the results of the three first series of experiments in several tables, exhibiting the difference between the percentage and absolute quantity of carbonic acid gas in the expired air at various periods, after the suspension of the respiratory movements under the circumstances mentioned, and when the respiratory movements proceed in the normal manner. In the first series of experiments, the percentage of the carbonic acid in the expired air, after the respiratory movements had been suspended 20 seconds, was higher by 1·73 than when these movements were normal, but the absolute quantity evolved from the lungs had diminished by 2·642 English cubic inches, and at the end of 55 seconds its percentage had increased 2·32, but its absolute quantity had diminished to the extent of 12·382 cubic inches. In the second series of experiments, where the deepest possible inspiration preceded, and the deepest possible expiration followed, the suspension of the respiratory movements, the absolute quantity of carbonic acid gas evolved from the lungs, for the first 15 seconds, was somewhat more than what would have occurred had these movements proceeded in the normal manner, but after this it began to diminish; and when the respiratory movements had been suspended for 95 seconds, it was diminished to the extent of 14·078 English cubic inches, though its percentage had considerably increased. At the end of the 100 seconds, the percentage of the expired air was 3·08 above the normal quantity in ordinary respiration. In the third series of experiments, the carbonic acid in the expired air, at the end of 30 seconds, was 1·55 per cent. above the normal quantity. These experiments prove, therefore, that when the respiratory movements have been suspended for a time, the percentage of carbonic acid in the expired air will increase, but the absolute quantity evolved from the lungs will be diminished, so that the increase in the percentage of this gas does not by any means compensate for the diminished quantity of air passing through the lungs.

When the same air is breathed more than once, the quantity of carbonic acid in it is increased. Allen and Pepys * state that air, passed 9 or 10 times through the lungs, contained 9·5 per cent. of carbonic acid gas; and the greatest quantity obtained, in air breathed as often as possible, was 10 per cent. Mr. Coathupe † found the average quantity of carbonic acid gas, in air in which warm-blooded animals had been confined until they were becoming comatose, to be 10·42 per

* Philos. Transact. of London for 1808.
† Opus cit.

cent.; while, if they were allowed to remain in it until they had become asphyxiated, it contained 12·75 per cent. Vierordt, in three experiments, breathed, from 1½ to 3 minutes, a volume of air amounting to 427 English cubic inches, and found, on an average, the carbonic acid gas 1·5 per cent. above that contained in air breathed only once.

The percentage of carbonic acid in the expired air differs at different periods of the same expiration. As the air expelled in the first part of an expiration consists chiefly of that contained in the trachea and upper part of the air passages, its amount of carbonic acid gas must necessarily be smaller than that expelled at a later period of the expiration. Allen and Pepys found the carbonic acid gas in the first and last portions of air in a deep expiration to differ as widely as 3·5 and 9·5 per cent. Dalton states that while the average carbonic acid in an ordinary expiration is 4 per cent., the last portion of a forced expiration contains 6 per cent. Vierordt divided the air of an ordinary expiration as far as possible into two equal parts, and in twenty-one experiments ascertained that while the average quantity of carbonic acid in the whole expiration was 4·48, the first half contained 3·72 per cent., and the last half 5·44 per cent. We have already seen, that Vierordt concludes from his experiments that the air, after a sojourn of about 40 seconds in the respiratory apparatus, has the same percentage of carbonic acid gas in the different parts of the lungs and air passages.

From the above details, it must be obvious that nearly all the attempts made to estimate exactly the average quantity of carbon evolved in the form of carbonic acid gas from the body in the 24 hours are entitled to very little confidence. The greater number of these are founded on a few experiments performed upon one or a very small number only of individuals in a state of rest, and upon the result of a few respirations in some cases performed under constraint. The estimate of the amount of loss of carbon in the 24 hours from the lungs and external surface of the body, based upon the direct method of experiment, in which the greatest number of the circumstances that influence the evolution of carbonic acid gas from the lungs were taken into account, is undoubtedly that of Scharling, though this even must be regarded as an approximation only to the truth. Suppose we take the average estimate of the two adult males between 28 and 35 years of age for the 24 hours, as given by Scharling *, the loss of carbon by the lungs and skin is 3543·13 Troy grains, or 7·382 oz. Troy. † Liebig ‡ has endeavoured to ascertain the quantity of carbon lost at the lungs and skin in the 24 hours by the indirect method of research, which he maintains to be by far the most trust-worthy. He proceeded to ascertain the quantity of charcoal in the daily food and drink of a body of soldiers, and after deducting the comparatively small quantity of this substance that passes off in the fæces and urine, the remainder was taken as the amount of carbon that unites with oxygen, and escapes in the form of carbonic acid gas by the lungs and skin. From the data thus obtained he calculates that an adult male, taking moderate exercise, loses 13·9 oz. of carbon daily by the lungs and skin; and that 37 oz. of oxygen gas must be daily absorbed from the atmospheric air for the purpose of converting this charcoal into carbonic acid gas. From similar experiments upon the inmates of the Bridewell at Marienschloss (a prison where labour is enforced), he calculates that each individual lost in this manner 10·5 oz. of carbon daily; while in another prison, where the inmates were deprived of exercise, this loss amounted only to 8·5 oz. daily.* Allowing that this indirect method of research is more accurate than the direct, — a point which we are not at present prepared to determine, — the accuracy of the data upon which Liebig's inferences rest regarding the quantity of carbonic acid exhaled from the lungs and skin in an adult using moderate exercise, has been called in question by Scharling.† He endeavours to prove, by an analysis of the food and drink allowed to the sailors on board of his Danish Majesty's vessels of war, that the whole carbon taken daily into the body of each of these individuals must be somewhat less than 10½ oz.; yet these sailors are subjected to harder work than ordinary seamen.‡

The quantity of carbonic acid gas evolved from the body in respiration varies greatly in the different divisions of the animal kingdom. It is greater in birds, in proportion to their bulk, than in the cold-blooded vertebrata, and still smaller in the invertebrata, with the exception of insects.§ The ascertainment not

* Vide table given in p. 26.

† The estimates of the average loss of carbon, in the form of carbonic acid gas, from the lungs in the twenty-four hours by other experimenters, differ considerably. Lavoisier and Seguin estimated the loss of carbonic acid gas at 14,930 cubic inches, which they believed would yield 2776·304 grains Troy; Messrs. Allen and Pepys at 39,534 cubic inches of carbonic acid gas, containing rather more than 11 oz. Troy of carbon; and Mr. Coathupe at 10,666 cubic feet of carbonic acid gas, yielding 2386·27 grains, or 5·45 oz. avoirdupois. Vierordt, from numerous experiments on himself, ascertained that when in a state of rest the quantity of carbonic acid gas exhaled from the lungs per minute was for the maximum 452 cubic centimètres (27·572 Eng. cub. in.), for the minimum 177 cub. cent. (10·797 Eng. cub. in.), and for the average 261 cub. cent. (12·261 Eng. cub. in.), so that the relation of the minimum and maximum was 100 : 255. If the quantity of carbonic acid evolved from the lungs differs so much at different times in the same individual in the minute, and is so materially influenced by the varying conditions of the body, how difficult must it be to ascertain the average quantity during the twenty-four hours.

‡ Animal Chemistry, &c., edited by Dr. Gregory, p. 13; 3rd edit. 1846.

* Opus cit. p. 46.

† Annalen der Chemie und Pharmacie, von Wöhler und Liebig, Band lvii. S. 1. 1846.

‡ Opus cit. p. 9.

§ The results of the various experiments upon

only of the absolute quantity of carbon which escapes from the body in the form of carbonic acid gas in the different classes of animals, but also the relative proportion of this to the weight of the body, is a matter of considerable physiological interest, especially with reference to the source of animal caloric. From the experiments of Scharling, Andral, and Gavarret, it is evident that the young of the human species relative to their weight consume considerably more oxygen gas, and evolve more carbonic acid gas by respiration, than the middle-aged; and that the latter again evolve more carbonic acid than those far advanced into old age. Valentin and Brunner have calculated, from experiments performed on Valentin, who at the time was 33 years of age, that for every gramme weight (15·433 Troy grains) of his body, there was evolved ·0089 Troy grain of carbonic acid gas, containing ·0024 Troy grain of carbon; and this calculation approximates pretty closely to one based upon the results of Andral and Gavarret upon the evolution of carbon, combined with those of Quetelet upon the average weight of the body at this period of life. * The following table, calculated from the experiments of different observers, to show the quantity of carbon consumed in the 24 hours for every 100 grammes weight (1543·3 Troy grains) of the body in the four divisions of the vertebrata, is given by Vierordt: —

| | Troy Grains. | |
|---|---|---|
| Tench (Provençal and Humboldt) | ·370 = | 1 |
| Frog (Marchand) | 1·342 = | 4 |
| Man (Scharling) | 4·506 = | 12 |
| Pigeon (Boussingault) | 42·317 = | 114 |

*Quantity of oxygen absorbed at the lungs.* — That a quantity of oxygen gas greater than what is necessary to form the carbonic acid gas in the expired air disappears from the inspired air, is now placed beyond a doubt. The quantity of oxygen gas that disappears from the inspired air by absorption at the lungs is not uniform, even in the same individual, for any length of time, and the variations in this respect are in all probability determined by the same circumstances which affect the evolution of carbonic acid gas, the absorption of oxygen being increased when the evolution of carbonic acid is increased, and *vice versa.* Dalton calculated that he himself respired 500 cubic feet of atmospheric air, containing 105 cubic feet of oxygen, in the 24 hours, and that 25 cubic feet of the oxygen, weighing 15,120 grains, or 2·6 lbs. Troy, were absorbed at the lungs. Valentin and Brunner, in 34 analyses of the air expired by 3 individuals between 33 and 54 years of age, found the *average* quantity of oxygen gas to be 16·033, the *maximum* 17·246, and the *minimum* 14·968 parts by volume in the 100 parts of the expired air. Proceeding on these results of Valentin and Brunner, we may estimate the average amount of oxygen that disappears from the inspired air at 4·78 by volume in the 100 parts.

While the experiments upon the relation of the quantity of oxygen absorbed at the lungs to that of the carbonic acid gas evolved, made by Lavoisier, Sir H. Davy, and Dalton on the human species, by Legallois, Dulong, Despretz, and Dr. W. F. Edwards upon the warm-blooded animals, by Treviranus upon several cold-blooded animals, and by Marchand upon frogs, all concur in making the oxygen absorbed greater than what is necessary to form the carbonic acid exhaled, they exhibit very considerable differences in the relative proportions of the absorbed oxygen and exhaled carbonic acid gas. In some of these experiments, the oxygen absorbed was considerably greater than what is necessary to form the carbonic acid gas. In Marchand's experiments on frogs subjected to prolonged fasting, the relation of the oxygen absorbed to the carbonic acid evolved constantly increased, until it amounted to between 410—430 : 100. * Valentin and Brunner, in their experiments on the human species, found the relative proportions of these two gases to approximate so closely to their diffusive volumes, that they believed the small difference between the results obtained by actual experiment and when calculated according to the law of the diffusion of gas, discovered by Graham, arose from incidental circumstances; and as the diffusive volume of carbonic acid gas is to oxygen gas as 1 : 1·1742, they maintain that for every 1 volume of carbonic acid gas evolved from the blood, 1·1742 volume of oxygen gas is absorbed. Valentin has given the following table, constructed from facts furnished by Quetelet, Andral, and Gavarret, conjoined with calculations of the relative quantities of oxygen absorbed and carbonic acid evolved according to the law of the diffusion of gases, to exhibit the weight of the body, the quantity of carbon consumed in respiration, and the probable amount of oxygen absorbed and carbon consumed at the different periods of life in the human species †: —

the quantity of carbonic acid evolved in respiration in different classes of animals up to the period when the work was published, are thrown into a tabular form in Burdach's Physiologie, 2nd edition, translated by Jourdan, tom. ix. p. 512.

* A table constructed on these data, exhibiting the probable quantity of carbon which combines with oxygen to form the carbonic acid gas evolved at the lungs at different ages in the human species, is given at p. 569 of Valentin's Lehrbuch.

* At page 563 of Valentin's Lehrbuch are two tables exhibiting the relative proportions of oxygen gas absorbed and carbonic acid evolved, as ascertained by direct experiment, and as calculated according to the law of the diffusion of gases. We shall have occasion to make some remarks on this subject when we come to discuss the theory of respiration.

† Opus cit. p. 571. The weights and measures in the original table are here reduced to Troy weight and English cubic inches.

| Years of age. | Average weight of body in Troy pounds. | Carbon consumed, in Troy grains. | | Quantity of oxygen which disappears from the inspired air. In grains. | | Overplus of oxygen above what is necessary to form the carbonic acid gas. In Troy grains. | | Volume of oxygen that disappears from the inspired air under a pressure of 29·92 inches, and a temperature of 32° F. In English cubic inches. | |
|---|---|---|---|---|---|---|---|---|---|
| | | In 1 hour. | In 24 hours. | In 1 hour. | In 24 hours. | In 1 hour. | In 24 hours. | In 1 hour. | In 24 hours. |
| 8 | 59·62 | 77·165 | 1864·306 | 240·955 | 5782·806 | 35·233 | 845·604 | 526·907 | 12645·770 |
| 15 | 124·34 | 134·267 | 3222·410 | 419·252 | 10062·069 | 61·207 | 1468·974 | 1154·142 | 27699·422 |
| 16 | 143·05 | 166·676 | 4000·233 | 520·447 | 12490·852 | 75·976 | 1823·139 | 1432·669 | 34384·076 |
| 18—20 | 164·13 to 174·15 | 175·936 | 4222·468 | 549·399 | 13184·782 | 80·359 | 1928·631 | 1512·132 | 36298·371 |
| 20—24 | 171·15 to 181·36 | 188·282 | 4518·782 | 587·904 | 14110·083 | 85·622 | 2054·934 | 1618·436 | 38842·098 |
| 40—60 | 184·36 to 175·49 | 155·873 | 3740·959 | 486·710 | 11681·052 | 71·099 | 1706·395 | 1339·847 | 32156·346 |
| 60—80 | 175·49 to 164·02 | 141·983 | 3407·606 | 443·34 | 10640·250 | 64·926 | 1558·239 | 1220·478 | 29291·495† |

From the details given above we may obtain information of considerable importance on several practical points. A consideration of the large quantity of atmospheric air passing through the lungs in the 24 hours, and the extent to which it is vitiated by this in the removal of a part of its oxygen and the substitution of a quantity of carbonic acid gas, will assist us in acquiring definite information regarding the amount of ventilation required in the apartments of our private and public buildings. It appears that between 400 and 500 cubic feet of atmospheric air pass daily through the lungs of an adult enjoying moderate exercise; and the estimate of Dalton, that 23 cubic feet of oxygen gas are, during the same period, absorbed at the lungs, is probably not far from the average. The same air cannot be breathed twice without inducing prejudicial effects, so that at each inspiration entirely fresh air ought to be supplied, or the air already breathed ought to be so largely diluted by the admission of fresh air as to be restored very nearly to its original composition. Leblanc informs us, that in the Chamber of Deputies in Paris, where the system of ventilation is based upon the principle of furnishing to each individual from 10 to 20 metres cubes (353·316 to 706·331 English cubic feet) of air per hour, the air issuing from the apartment contained from 2 to 4 of carbonic acid gas in the 1000 parts by weight.* The quantity of pure atmospheric air here furnished is probably somewhat insufficient, if the presence of 1 part of carbonic acid in the 100 of atmospheric air be likely to act prejudicially when breathed for a long time continuously. From Dr. Snow's experiments, it appears that the prejudicial effects of breathing air deteriorated by respiration, is not entirely due to the presence of an increased quantity of carbonic acid gas, but also in a considerable degree to the diminution of the oxygen. He found that birds and mammalia introduced into an atmosphere containing only from 16 to 10½ per cent. of oxygen soon died, though means were adopted for removing the carbonic acid formed by respiration.* The increase of the carbonic acid gas to 12 and 20 per cent., provided the oxygen gas was still as high as 21 per cent., did not appear to enfeeble the vital actions more rapidly than the diminution of the oxygen to the extent above stated. Any notable diminution in the percentage of the oxygen gas, even when no carbonic acid is present, cannot take place without danger to the warm-blooded animals†, and the carbonic acid in the air respired acts more or less energetically in destroying life, as it has been produced at the expense of the oxygen of the air, or been added to it already formed.‡

* Annales de Chimie et de Physique, troisième série, tom. v. p. 241. 1842. In the Model Prison at Pentonville from 30 to 45 cubic feet per minute, or from 1800 to 2700 cubic feet per hour, of pure fresh air is made to pass into every cell. (Report of the Surveyor-General on the Construction, &c. of Pentonville Prison. 1844.)

* Edinburgh Medical and Surgical Journal, vol. lxv. 1846. A green-linnet was confined in a vessel containing 2000 cubic inches of air, consisting of 16 of oxygen and 84 of nitrogen in the 100 parts by volume, and it died in ten minutes. A mouse was introduced into the same vessel filled with air containing 10½ per cent. of oxygen, and in five minutes it was no longer able to stand.

† There is a marked difference in this respect between the cold-blooded and warm-blooded animals. Vauquelin (Annales de Chimie, tom. xii. p. 271. 1792) in his experiments upon some snails, found that when confined in a quantity of air, all the oxygen had disappeared at the time of their death; and Spallanzani observed the same thing in a few of his experiments on the same animals. Matteucci (Leçons sur les Phénomènes Physiques des Corps Vivants, p. 115. 1847), obtained similar results on a torpedo confined in a limited quantity of water.

‡ Dr. Snow infers from his experiments on the lower animals that in the human species "five or

The experiments on the effects of diminished frequency of the respirations in reducing the amount of carbonic acid gas evolved from the blood in a given time, are in accordance with observations made on the state of the blood and its circulation, when this condition has been induced in man or in the other warm-blooded animals. A diminution in the frequency of the respiratory movements occasionally occurs to a notable extent in the course of some diseases, and this deserves the careful attention of the practitioner, as it is likely to lead to very serious consequences.*

The greater length of time that the respirations may be suspended without inducing insensibility, when a deep expiration followed by a deep inspiration has immediately preceded, affords additional illustration of the procedure which a person ought to adopt when he wishes to suspend, during diving, &c., the respirations for the longest period consistent with his safety. The manner and the order in which the vital actions are brought to a stand when the chemical changes between the blood and the atmospheric air are arrested, have been discussed under the article ASPHYXIA.†

six per cent. by volume of carbonic acid gas cannot exist in the air without danger to life, and that less than half this amount will soon be fatal, when it is formed at the expense of the oxygen of the air." (Opus cit. p. 54.) Leblanc ascertained that an addition of 3 or 4 per cent. by weight of carbonic acid formed by the combustion of charcoal, and at the expense of the oxygen of the air respired, proved instantly fatal to dogs, while it required the addition of 30 or 40 per cent. of pure carbonic acid gas to the atmospheric air to produce the same effect. The great activity of air deteriorated by the burning of charcoal in producing asphyxia, Leblanc attributes to the presence of carbonic oxide. He states that birds placed in air containing one per cent. of this gas, die in two minutes (Opus cit. pp. 240 and 245). Legallois (Annales de Chimie et de Physique, tom. iv. p. 113. 1817) had previously performed experiments, from which it may be inferred that an addition of somewhat more than 20 per cent. of carbonic acid to the atmospheric air, is sufficient to bring the evolution of carbonic acid from the blood in the lungs to a stand in the warm-blooded animals, and that, when the percentage of carbonic acid in the inspired air is increased to above 30, part of this gas is absorbed by the blood.

* We have given some illustrations of this in pointing out the manner in which division of the vagi nerves causes death. (Edinburgh Medical and Surgical Journal, vol. li. p. 298 to 302. 1839.)

† We have published a series of experiments (Edinburgh Medical and Surgical Journal, vol. lv. 1841) which go to support the account given of the manner in which the vital actions are arrested in asphyxia in the *article* referred to. In this we obtained satisfactory proof of the opinion of Bichat upon the effects of the venous blood in suspending the sensorial functions. In an excellent experimental essay on this subject, published subsequently to our essay (Edinburgh Med. and Surg. Journal, vol. lxiii. 1845), the author maintains, in opposition to the doctrine laid down in the article ASPHYXIA, "that the flow of blood through the lungs is arrested in consequence of the venous blood acting as an excitant to the minute branches of the pulmonary veins and causing their contraction." In our experiments we found that, when the suspension of the respiration had been carried so far as to arrest the flow of blood through the lungs, the admission of atmospheric air was *instantaneously* followed by the renewal of the passage of the blood to the left side of the heart, — a fact incompatible with this opinion, seeing that the blood-vessels are endowed with that kind only of contractility which manifests itself by slow contractions and equally slow relaxations.

Experiments have been made by Nysten*, by Mr. Macgregor†, Dr. Malcolm‡, and by Hannover§, upon the quantity of carbonic acid gas evolved from the lungs in some diseases, but these have not yet been carried sufficiently far to furnish us with any practical or theoretical conclusions of importance.

*Differences between arterial and venous blood.* — A knowledge of the chemical and physical differences between arterial and venous blood, or, in other words, between the blood immediately before and immediately after it has passed through the lungs and been subjected to the action of the atmospheric air, constitutes part of the data requisite for discussing the Theory of Respiration. Although many able chemists and physiologists have of late years directed their attention to this subject, yet, from its inherent difficulties, much discrepancy of observation and conflicting evidence still require to be cleared up and reconciled. Most, if not all, of the comparative analyses of the venous and arterial blood hitherto published are of considerably less value for our present purpose than they may at first appear, since only those of the venous blood flowing from the right side of the heart, and the arterial blood flowing from the left side of the heart or along the arteries, ought properly to be taken into account. The blood returning along the veins of the abdominal viscera, and entering the heart by the cava inferior, differs in composition from that entering the heart by the cava superior, for, independently of other reasons, a quantity of water and certain substances taken into the stomach are absorbed by the mesenteric and gastric veins. The composition of the blood in the large veins at the lower and lateral parts of the neck must also be somewhat affected by the lymph and chyle poured into that portion of the venous system. The analyses of venous and arterial blood taken at the same time from the carotid artery and the jugular vein, — the plan most generally followed in these researches, — are better fitted for throwing light upon the changes the blood undergoes in the perform-

* Recherches de Physiologie et de Chimie Pathologique. Seconde section. 1811.

† Edinburgh Monthly Journal of Medical Science, vol. iii. p. 1. 1843.

‡ Transactions of British Scientific Association, for 1840, p. 87.

§ De Quantitate relativa et absoluta Acidi Carbonici ab Homine sano et ægroto exhalati. 1845. Hannover, in his experiments, employed the apparatus of Scharling, and was enabled to ascertain the *absolute* quantity of carbonic acid evolved from the body; while the other experimenters ascertained its percentage only. There can be no doubt that the plan adopted by Hannover is the one which ought to be followed.

ance of nutrition and secretion than of respiration.

The most marked difference, more especially in warm-blooded animals, between arterial and venous blood is that of colour, — arterial blood being of a scarlet red, and venous blood of a dark Modena hue. The extent of this difference of colour between the blood in the arteries and in the veins varies in the different vertebrata, and is greater in birds and in the mammalia than in reptiles and fishes ; and it also varies in different conditions of the body and surrounding media in the same animal. In animals exposed to artificial high temperatures*, or living in warm climates†, when the energy of the respiratory function is naturally diminished, the venous blood may be of a brighter colour than usual, while the arterial may be less so, and it may then be difficult to distinguish the one kind from the other. In certain cases of high febrile excitement of the circulation, as in acute rheumatism when the blood passes rapidly and abundantly through the lungs, the blood in the veins may be of a scarlet colour: on the other hand, where the aëration of the blood is imperfect, as during the state of hybernation, in certain diseases, or from some mechanical impediment to the free passage of the air into the lungs, the blood flowing along the arteries approaches more or less the dark colour of venous blood.

The temperature of the arterial blood in the left side of the heart, aorta, and large vessels springing from it, is higher than the venous blood by from 1° to 2° Fahr., according to Dr. John Davy ‡, and 1°·01 C (1°·818 Fahr.) on an average, according to Becquerel and Breschet. § According to Dr. Davy, the capacity of venous blood for caloric is 852, that of arterial blood 839. ||

The specific gravity of venous is somewhat greater than that of arterial blood. Dr. Davy gives the specific gravity of arterial blood as 1050, that of venous as 1053. ¶ Some of those who have published analyses of both kinds of blood, procured more solid materials and less water from venous than from arterial blood; others again have obtained the opposite result; while Denis, in his analysis of the blood of a dog, observed no difference in this respect. The number of instances, — taking the more trust-worthy analyses only into account, — where the quantity of water was greater in the arterial than in the venous blood decidedly preponderates. In all probability the relative quantity of water in the two kinds of blood is determined by the relative extent of the loss of that fluid by the arterial blood at the kidneys, lungs, skin, &c., and of the supply entering the veins from without, but chiefly through the mesenteric veins.

A larger quantity of fibrin has been obtained by some analysts from arterial than from venous blood in man and in the domesticated animals; others again have procured a larger quantity from venous than from arterial blood; while a few have obtained dissimilar results in their analyses of these two kinds of blood in different genera of animals, and even in different individuals of the same species.* In the greater number of the analyses, however, more fibrin was obtained from arterial than from venous blood. † According to Denis and Scherer, the fibrin of the two kinds of blood differs in regard to its solubility in nitre. When a portion of well-washed fibrin from venous blood is triturated with a third part of nitre, and four times its weight of water, and a small quantity of caustic potass or soda is then added, it dissolves into a gelatinous mass, having the chemical characters of albumen; while the fibrin from arterial blood similarly treated undergoes no such changes.

The blood-corpuscles are more abundant in arterial than in venous blood, according to Prevost and Dumas, Lecanu and Denis ; according to Meyer, Hering, and Nasse, they are more abundant in the venous blood; while the analyses of Letellier and Simon tend to show that the proportion is fluctuating. According to Simon, the blood-corpuscles of arterial contain less hæmatin than venous blood, while the quantity of globulin is variable. Mulder states that the chemical composition of hæmatin is the same whether derived from arterial or venous blood.‡

The statements made regarding the relative proportions of the albumen, fat, osmazone, and salts in the two kinds of blood, differ too much to justify us in attaching any importance to them, — a remark which, as yet, we are afraid applies with too much truth to most of the other statements regarding the chemical differences between the two kinds of

* Crawford. Experiments and Observations on Animal Heat, p. 309. 3rd edit.

† Dr. J. Davy. London Phil. Transact. for 1838, p. 28.

‡ Researches, Physiological and Anatomical, vol. i. p. 147. 1839. At page 211 of the same volume, another series of experiments is given, in which the difference in temperature varied from 1° to 3° F.

§ Annales des Sciences Naturelles, 2me série, tom. vii. p. 94. 1837. Becquerel and Breschet, in their experiments, used a thermo-electric apparatus. They found the difference of temperature between the two kinds of blood diminish as the blood-vessels are more distant from the heart.

|| Researches, Physiological and Anatomical, vol. i. p. 146.

¶ Opus cit. vol. ii. p. 22.

* Nasse (article Blut, in Wagner's Handwörterbuch der Physiologie, Band i. S. 171) states that the difficulty of conducting a correct quantitative analysis of the fibrine of the blood is sufficient to account for these discrepancies.

† We refer those who may wish to obtain more detailed information upon this and some other points connected with the chemical differences between the arterial and venous blood, with references to the different authors who have investigated this subject, to Nasse's Treatise, entitled Das Blut, &c., and the article by him in Wagner's Handwörterbuch already referred to, and the first volume of Simon's Animal Chemistry, translated for the Sydenham Society, by Dr. Day.

‡ The Chemistry of Vegetable and Animal Physiology. Translated from the Dutch by Fromberg. Part II. p. 334.

blood, mentioned above. Michaelis *, and Marcet and Macaire †, in their ultimate or elementary analyses of both kinds of blood, found more carbon and less oxygen in venous, and less carbon and more oxygen in arterial blood; but Berzelius has adduced sufficient reasons to induce us to doubt whether, in such investigations, at least as at present conducted, the distinctive characters of the two kinds of blood can be preserved during the analysis, and that they are deserving of any confidence.‡

A larger quantity of fixed carbonic acid has been obtained from venous than from arterial blood by Mitscherlich, Gmelin, and Tiedemann.§

It is now placed beyond dispute that *free* gases exist in the blood, and it becomes a point of great importance in deciding upon the true theory of respiration to ascertain their nature, quantity, and relative proportions in the two kinds of blood. Four methods have been followed in procuring the free gases from the blood. 1. By the application of heat. 2. By the use of the air-pump. 3. By agitation of the blood with other gases. 4. By the respiration of other gases than atmospheric air.

The first of these methods is imperfect, as the albumen coagulates when the temperature is raised towards the boiling point, and may retain gases present in the blood. The second method is also liable to lead to negative results, unless the air-pump employed be of the best construction, for, according to Magnus, it is not until the pressure of the air within the bell-glass is reduced to one inch, that the gases begin to escape from the blood. In such experiments it is also necessary to employ blood from which the fibrin has been removed, for coagulated blood will retain the free gases, and prevent their escape.

Sir H. Davy stated that by raising the temperature gradually to 200 Fahr., he obtained from 12 cubic inches of the arterial blood of a calf $1\frac{1}{10}$ cubic inch of carbonic acid gas, and $\frac{7}{10}$ of a cubic inch of oxygen ‖; and that he procured carbonic acid gas from human venous blood heated to 112 Fahr.¶ Enschut assures us that, by subjecting blood to the temperature of boiling water, he obtained carbonic acid gas both from venous and arterial blood, and a greater quantity from the former than the latter kind of blood.* It is alleged that Brande obtained carbonic acid gas both from venous and arterial blood in considerable quantity by the use of the air-pump †; and Scudamore states that he procured it by the same means in variable quantities from venous blood.‡ Collard de Martigny § and Enschut ‖ procured carbonic acid gas both from venous and arterial blood, by placing them in the Torricellian vacuum, and a larger quantity from the former than from the latter. Nasse, sen.¶, Stevens**, Dr. G. Hoffman ††, Enschut ‡‡, Dr. Maitland §§, and Bischoff ‖‖, obtained carbonic acid gas from venous blood on agitating it with hydrogen, or by allowing this gas to stand over the blood for several hours. The existence of free carbonic acid gas in the blood was still, however, regarded by some physiologists as very problematical, since several trust-worthy and careful experimenters, such as Dr. J. Davy ¶¶, Mitscherlich, Gmelin,

* Diss. Inaug. de Partibus Constitutionis singularium Partium Sanguinis arteriosi et venosi. Berolini, 1827.

† Annales de Chimie et Physique, tom. li. p. 382. 1832.

‡ Lehrbuch der Chemie, Band iv. S. 99, 100. Dresden, 1831.

§ Zeitschrift für Physiologie, Band v. 1833. Mitscherlich, Gmelin and Tiedemann, by the addition of acetic acid, and the application of heat, obtained from 1000 parts of venous blood at least 12·3 parts, and from the same quantity of arterial blood 8·3 parts of combined carbonic acid.

‖ Beddoes' Contributions to Physical and Medical Knowledge, p. 132. 1799.

¶ Idem opus, p. 134.

* Dissertatio Physiologico-Medica de Respirationis Chymismo, p. 96 to 99. 1836. Enschut, in one set of experiments, obtained in this manner from 40 cubic centimètres (2·440 English cubic inches) of each kind of the blood of the calf, 2 to 4 cubic centimètres (·12205 to ·24410 English cubic inches) of carbonic acid gas from venous blood, and 1 to 2·5 cubic centimètres (·061025 to ·15256 English cubic inches) of the same gas from arterial blood, p. 99. Enschut points out various precautions necessary to be observed to secure accuracy in such experiments, a want of attention to which, he believes, was the cause of the failure of Dr. J. Davy, Müller, and others, in their attempts to obtain carbonic acid gas from blood by heat, p. 100—104.

† Sir Everard Home, in London Philos. Trans. vol. xxix. p. 172. 1818. It is stated by Sir Everard (p. 181), that Mr. Brande obtained carbonic acid in the proportion of 2 cubic inches for every ounce of blood,—a quantity so large, and obtained apparently with such facility, as to raise insuperable suspicions regarding the accuracy of the experiments. Sir Everard Home (29th vol. Philos. Trans. p. 189) and Scudamore state that they observed the escape of free carbonic acid gas from the blood during its coagulation,—an observation not confirmed by others. It appears that Vogel also obtained carbonic acid from venous blood by means of the air-pump. (Schweigger's Journal, Band xi. S. 401, as quoted by Bischoff.)

‡ An Essay on the Blood, p. 108. 1824. The largest quantity of carbonic acid gas that Scudamore procured from venous blood, was half a cubic inch of gas from six ounces of blood.

§ Magendie's Journal de Physiologie, tom. x. p. 127. 1830.

‖ Opus cit. p. 115.

¶ Meckel's Archiv, Band ii. 1816. Nasse allowed the hydrogen to stand over blood from 24 to 48 hours.

** Philos. Transact. vol. xlvi. p. 345. 1835.

†† Medical Gazette, for 1832—1833, vol. xi. p. 881.

‡‡ Diss. de Respirationis Chymismo, p. 124 to 126. Enschut obtained carbonic acid by this means also from arterial blood, but in smaller quantities than from venous blood.

§§ Experimental Essay on the Physiology of the Blood, p. 52. Edinburgh, 1837.

‖‖ Commentatio de Novis quibusdam Experimentis Chemico-Physiologicis ad illustrandam Doctrinam de Respiratione institutis, pp. 17, 18. Heidelberg, 1837. Bischoff also procured carbonic acid gas from arterial blood by means of the air-pump, pp. 11, 12.

¶¶ Philos. Trans. vol. xxxiv. p. 506. 1823.

and Tiedemann *, Stromeyer †, Müller and others ‡, failed in obtaining any carbonic acid gas from the blood by the air-pump and other means, and it was not until the publication of the important experiments of Magnus, confirmed as they have been to a certain extent by other observers, and strengthened by evidence collected both before and since on the results of the respiration of animals in hydrogen and nitrogen gases, that the existence of any free gas in the blood has been generally admitted. Bertuch and Magnus procured carbonic acid gas from human venous blood by agitating it with hydrogen.§ Magnus has not only obtained carbonic acid gas from both kinds of blood in some of the domesticated animals, but also oxygen and azote by means of the air-pump. The two latter gases were also procured from both kinds of blood by agitation with carbonic acid gas. The quantity of gases obtained from the blood by the air-pump in these experiments by Magnus amounted to $\frac{1}{10}$th, and sometimes to $\frac{1}{8}$th of the volume of the blood employed; but from the difficulty of liberating the gases from the blood, he believes that this quantity forms but a small part of that actually held in solution in this fluid. In some experiments with hydrogen, the quantity of carbonic acid obtained amounted to $\frac{1}{5}$th of the volume of the blood employed. The relative quantity of oxygen gas to the carbonic acid gas is greater in arterial than in venous blood. In venous blood the oxygen was as $\frac{1}{4}$th, and often $\frac{1}{8}$th, while in arterial blood it was at least as $\frac{1}{3}$d and sometimes $\frac{1}{2}$ to the carbonic acid.|| Magnus, in a second memoir on this subject, states that he obtained the following quantities of oxygen and nitrogen from the arterial blood of two old horses, by agitating it in carbonic acid gas : —

| Oxygen. | Azote. | |
|---|---|---|
| 10·5 | 2·0 | per cent. of the volume of blood employed.¶ |
| 10 | 3·3 | |

By adding together the *total quantity* of gases collected from each kind of blood in his different experiments by means of the air-pump, and then comparing the relative proportions of their constituent parts, the following results are obtained : —

| | Arterial blood. | Venous blood. |
|---|---|---|
| | Cubic centimètres. | Cubic centimètres. |
| Carbonic acid gas | 39·5 or 62·3 per cent. | 47·5 or 71·6 per cent. |
| Oxygen - - | 14·7 — 23·2 — | 10·1 — 15·3 — |
| Nitrogen * - | 9·2 — 14·5 — | 8·7 — 13·1 — |

The quantity of oxygen gas procured from the blood of calves, oxen, and horses, previously agitated with atmospheric air, was not less than 10 per cent. and not more than 12 per cent. The blood can, however, absorb a greater quantity of oxygen and nitrogen than was collected in the experiments last-mentioned, for by repeatedly shaking blood with renewed quantities of carbonic acid gas to remove the whole of the oxygen and nitrogen gases it contained, and then agitating it in measured quantities of atmospheric air, he ascertained, by again measuring the atmospheric air, that the minimum quantity of oxygen absorbed amounted to 10 per cent., and the maximum to 16 per cent. The quantity of nitrogen procured in numerous experiments on the blood of calves, oxen, and horses, previously agitated with atmospheric air, was, when reduced to the temperature of 32 Fahr. and the mean barometric pressure, from 1·7 to 3·3 per cent. of the volume of the blood employed. The quantity of oxygen gas which blood is capable of absorbing from the atmospheric air, is, according to Magnus, from 10 to 13 times more than water can do under the same circumstances.† The experiments

* Loc. cit.

† Dissertatio Liberumne Acidum Sanguine contineatur. Göttingen, 1831.

‡ Two at least of these experimenters, viz. Dr. Davy and Gmelin, have since satisfied themselves that carbonic acid gas is evolved from blood under the air-pump. Dr. Davy (Philos. Transact. for 1838, p. 291) obtained it in small quantities both from venous and arterial blood, and Gmelin (Preface to Bischoff's Commentatio de Novis quibusdam Experimentis, &c.) also in small quantity from venous blood.

§ Poggendorff's Annalen der Physik und Chemie, Band xl. S. 583. 1837.

|| Idem opus.

¶ Poggendorff's Annalen, Band lxvi. S. 202. 1845. Enschut had, previous to Magnus's experiments, obtained azote from both kinds of blood, and in greater quantity from venous than from arterial blood. Opus cit. p. 159.

* Poggendorff's Annalen, Band lxvi. S. 189. Gay Lussac (Annales de Chimie et de Physique, 3me série, tom. x. p. 1. 1844), has brought forward various objections against the inferences drawn by Magnus from his experiments. He asserts that they lead to the conclusion that more carbonic acid gas exists in arterial than in venous blood. Magnus has replied, and on the whole successfully, to these objections of Gay Lussac (Opus cit. Band lxvi). He contends that as the quantity of gases procured was only a part of what the blood actually contained, and as the experiments were of different duration, it must lead to error to compare, as Gay Lussac has done, the relative quantities of carbonic acid gas obtained from corresponding quantities of the two kinds of blood; and that the legitimate mode of procedure under the circumstances of the case, is to compare, as has been done in the above table, the relative quantities of the whole of the gases procured from each of the two kinds of blood.

† Poggendorff's Annalen, Band lxvi. S. 202. In some experiments the quantity of nitrogen absorbed by the blood, when previously agitated with carbonic acid, was 6·5 per cent. Though these various results obtained by Magnus in his experiments have not been fully confirmed by others, indeed several experimenters, such as Enschut, Bischoff, and Dr. J. Davy, who succeeded in procuring carbonic acid gas both from venous and arterial blood, failed in obtaining decided evidence of the presence of oxygen gas, yet they appear to have been so carefully and repeatedly performed, that a belief in their general

of Dr. J. Davy, Mitscherlich, Gmelin and Tiedemann, Enschut and Magnus, prove that venous blood can absorb considerably more than its own volume of carbonic acid gas; and according to Mitscherlich, Gmelin and Tiedemann, and Enschut, more of this gas can be absorbed by arterial than by venous blood.*

Lehmann has endeavoured to ascertain the relative quantities of free and combined carbonic acid in the blood. In twelve experiments upon bullock's blood the average quantity of free carbonic acid in 1000 grammes (15433·0 Troy grains) of blood, was 0·132 gram. (1·937 grains) of free, and 0·6759 gram. (10·431 grains) of combined carbonic acid: or, estimating these quantities by volume, in 61·250 English cubic inches of blood, there were 4·271 cubic inches of free, and 21·968 cubic inches of combined carbonic acid.†

The results obtained on causing animals to breathe gases devoid of oxygen are in unison with those derived from direct experiment, and furnish additional evidence in proof of the existence of free gases in the blood. That a quantity of carbonic acid gas may be exhaled from the blood during the respiration of gases devoid of oxygen is proved by the experiments of Spallanzani* and Dr. W. F. Edwards† on the products of the respiration of snails confined in hydrogen and azote; those of Dr. W. F. Edwards ‡ on a fish (Cyprinus aureus) confined in water saturated with hydrogen; those of Dr. W. F. Edwards §, Collard de Martigny ||, Müller and Bergemann ¶, Bischoff** and Marchand ††, on frogs confined in hydrogen or azote; and those of Dr. W. F. Edwards ‡‡, upon the young of certain of the mammalia confined in hydrogen gas. The experiments of Nysten §§, in which he first exhausted the air, as far as possible, in the lungs of adult dogs, and then caused them to breathe hydrogen or azote; and those of Sir H. Davy ||||, and of Coutanceau and Nysten ¶¶, on the respiration of nitrous oxide and azote in their own persons, though not free from serious objections, are still, as far as they go, in favour of the opinion that free carbonic acid gas is contained in the blood.

In a former part of this article we have detailed several observations, both upon the human species and the lower animals, to prove that a quantity of azote is frequently exhaled in respiration. The experiments of Allen and Pepys ***, and Nysten †††, show that the exhalation of azote is considerably increased by breathing oxygen or hydrogen, or a mixture of these two gases, and thus afford additional evidence that free azote exists in the blood. Marchand concludes from his experiments on frogs, that when they are made to breathe pure oxygen gas, azote is evolved from the blood, and that when made to breathe pure hydrogen, both oxygen and azote are evolved from the blood.‡‡‡

*Differences in the form of the red corpuscles in venous and arterial blood.* — The physical

accuracy is justly almost universally entertained by physiologists. Marchand (Journal für praktische Chemie, Band xxxv. S. 391) is the only other chemist, as far as we are aware, who has procured oxygen gas from the blood. He ascertained, by qualitative but not by quantative analysis, that oxygen gas is contained in the venous blood of the dog.

It has been argued, and the objection is anticipated and examined by Magnus, that part of the carbonic acid gas obtained from the blood in the above experiments may not have existed in the free, but in the combined state in the blood. It has been proved by the experiments of Heinrich Rose (Poggendorff's Annalen, Band xxxiv. S. 149. 1835), and Marchand (Journal für praktische Chemie, Band xxxv. S. 389, 390. 1845), that when a solution of bicarbonate of soda is agitated with, or even exposed for some time to, atmospheric air or hydrogen, it gives off part of its carbonic acid, and becomes a sesquicarbonate; and if heat be now applied, an additional quantity of carbonic acid is given off, and it is reduced to the state of carbonate of soda. If, therefore, bicarbonate of soda exists in the blood, part of the carbonic acid gas obtained in the experiments of Magnus and others may have been derived from this source. The exact condition of the carbonates of soda in the blood is not known: indeed their existence there has lately been called in question by Enderlin (Annalen der Chemie und Pharmacie, Band xlix. S. 317) and Liebig (idem opus, Band lvii. S. 126. 1846), but without sufficient reason, as Marchand (Journal für praktische Chemie, Band xxxvii. S. 321. 1846), Lehmann (idem opus, Band xl.), and Moleschott (Holländische Beiträge, Band i. hedft ii. S. 163. 1847) have shown.

* Dr. J. Davy (Philos. Transact. for 1838, p. 298) has made an important observation on the absorbing capacity of the blood for carbonic acid under different circumstances. In two animals, one of which was killed by strangulation, the other by exhaustion of the air of the lungs by the air-pump, the blood of the former absorbed only 150 per cent., that of the latter 370 per cent.

† Journal für praktische Chemie, von Erdmann und Marchand, Band xl. S. 133. 1847.

* Mémoires sur la Respiration, p. 346 to 351.

† De l'Influence des Agens Physique sur la Vie, p. 449. 1824.

‡ Opus cit. p. 447, 448.

§ Opus cit. p. 442 to 447.

|| Magendie's Journal de Physiologie, tom. x. p. 122 to 124.

¶ Muller's Elements of Physiology, translated by Baly, vol. i. p. 354.

** Commentatio de Novis quibusdam Experimentis Chemico-Physiologicis, p. 20.

†† Journal für praktische Chemie, Band xxxiii. S. 154. 1844. Marchand thinks that in the experiments of those who preceded him, upon the respiration of frogs in hydrogen, that the gas employed must have contained some oxygen, as the animals lived longer than those used in his experiments where the gas was quite pure.

‡‡ Opus cit. p. 453 to 455.

§§ Recherches de Physiologie et de Chimie Pathologiques, p. 225 to 229.

|||| Researches, Chemical and Philosophical. Division II.

¶¶ Coutanceau's Révision des Nouvelles Doctrines Chimico-Physiologiques, p. 280 to 302. 1821. Coutanceau and Nysten breathed azote alone; and their experiments were regarded, even by Coutanceau himself, as "essais bien incomplets." Opus cit. p. 301, 302.

*** Philos. Trans. 1809, p. 404.

††† Recherches, &c. p. 230, 231.

‡‡‡ Opus cit. Band xxxiii. S. 154—159. Band xxxv. S. 386—389. Marchand does not distinctly state that he ascertained this by direct analysis of the expired gases.

conditions of the red corpuscles can be changed by the action of various agents, such as pure water, and solutions of certain neutral salts. By the action of the former, the corpuscles swell, become more globular, and reflect less light; by the action of the latter, they become smaller, thinner, somewhat bent and notched, and reflect more light. These changes are apparently dependent upon endosmotic and exosmotic currents, between the fluid contents of the red corpuscles and the surrounding fluid. It has been maintained that the red corpuscles of venous and arterial blood differ in their external form, — the former approaching in their shape those acted upon by water, the latter those subjected to the action of solutions of the neutral salts; and this change in the form of the corpuscles has been adduced as the cause of the difference in colour between arterial and venous blood. Kaltenbrunner *, Schultz †, H. Nasse ‡, Scherer §, Reuter ||, Mr. Gulliver ¶, and Harless **, have described various differences in the external form of the red corpuscles of the two kinds of blood, as observed by them under the microscope, from which some of them infer an increase in their power of reflecting light ††; while Burdach ‡‡, Müller §§, Bruch ||||, and Marchand ¶¶, have failed in detecting by the microscope any difference in their external form in the two kinds of blood.*** Those observers who have described differences in the shape of the red corpuscles in arterial and venous blood do not quite agree in their account of these. They agree, however, in this, that the red corpuscles are more turgid and less clear in venous than in arterial blood. Scherer describes the red corpuscles in arterial blood as biconcave, and those in venous blood as biconvex and decidedly swollen. Mr. Gulliver states that in all his experiments "the red corpuscles were reduced in size, both in breadth and thickness, by neutral salts, and in a less degree by sugar and oxygen; while the first effect of water and of carbonic acid was to swell the corpuscles and make them more globular." Nasse says that the red corpuscles of the arterial blood in the mammalia, on the contact of carbonic acid gas, become muddy in the middle, the ring formed by the colouring matter becomes broader, they become darker and somewhat thicker, at least on one side, and they adhere closer together. Harlass gives measurements of the corpuscles of the blood of the frog, when brought into contact with oxygen and carbonic acid, to show that they become somewhat broader and thicker when exposed to the action of the latter gas. He also states that while the corpuscles in the former are finely granulated on the external surface, those in the latter are smooth.

*Theory of respiration.* — The actions between the blood and the atmospheric air in the performance of the function of respiration are regulated entirely by chemico-physical laws. No doubt the blood and air are conveyed to and from the lungs through the instrumentality of the vital properties of the nervous and muscular tissues, but the changes they there undergo do not appear to be influenced by vitality. When venous blood and atmospheric air are brought into contact out of the body, the same actions apparently occur as in the lungs during life, viz., the atmospheric air loses part of its oxygen, acquires in its place a quantity of carbonic acid gas, and the blood assumes the arterial hue. The distribution of the blood in innumerable minute streamlets upon the surface of the air-cells, filled with atmospheric air, affords much more advantageous means than can be obtained in experiments out of the body, for facilitating the mutual actions of the blood and atmospheric air. From the known rapidity with which gases permeate both living and dead animal membranes, the moist delicate membranes that intervene between the blood contained in the capillaries of the lungs, and the atmospheric air in the air-cells, will readily permit the endosmose of a portion of the atmospheric air, and the exosmose of a portion of the gases held in solution in the blood.

The rest of our remarks on the theory of respiration may be arranged under three heads: viz. 1st, the manner in which the air in the upper and in the lower parts of the respiratory apparatus is intermixed; 2dly, the nature of the immediate actions between the blood and atmospheric air in the lungs, in which a quantity of carbonic acid gas appears in the expired, and a quantity of oxygen disappears from the inspired air; 3dly, the nature of the changes the blood undergoes in passing from the venous to the arterial condition.

* Experimenta circa Statum Sanguinis et Vasorum in Inflammatione, p. 71. 1826.

† Das System der Circulation, S. 27. 1836.

‡ Handwörterbuch der Physiologie, von Wagner, Band i. S. 97. 1842.

§ Zeitschrift Für Rationelle Medizin. Herausgegeben von Henle und Pfeufer, Band i. heft ii. S. 288. 1843.

|| Idem opus, Band iii. heft ii. S. 165. 1845.

¶ Work of Hewson, printed for the Sydenham Society, note at p. 9. 1846.

** Monographie über den Einfluss der Gase auf die Form der Blutkörperchen, von Rana temporaria. Erlangen, 1846.

†† We have not included, for obvious reasons, among these authorities in favour of there being a difference in the shape of the red corpuscles in the two kinds of blood, those authors who, like Henle and Mulder, have adopted this view without stating that they had personally investigated by the microscope the point at issue.

‡‡ Traité de Physiologie, &c. traduit par Jourdan, tom. vi. p. 135, 136. 1837.

§§ Elements of Physiology, translated by Baly, vol. i. p. 346. 1840.

|||| Zeitschrift, &c. Von Henle und Pfeufer, Band i. heft iii. S. 440. 1844; Band v. heft iii. S. 440. 1847.

¶¶ Journal für praktische Chemie, Band xxxviii. S. 279. 1846.

*** Dr. G. O. Rees (Med. Gazette, Session 1844-5, p. 840) maintains that the structure of the red particles prevents the possibility of their assuming any other form than the biconcave in a fluid of the specific gravity of serum, whether exposed to air or not; but this statement appears to be founded upon the presumed effects of the endosmotic and exosmotic conditions of the red corpuscles, and not upon any examination by the microscope of the effects of gases upon these bodies.

*On the manner in which the air in the upper and lower parts of the respiratory apparatus becomes intermixed.*—The respiratory qualities of the other parts of the inner surface of the air-passages must be very feeble when compared with the membrane of the air-cells of the lungs; and there can be no doubt that almost all the carbonic acid present in the expired air is derived from the blood circulating in the capillary blood-vessels of the air-cells; and that this evolution of carbonic acid gas is continuous, going on during expiration as well as during inspiration. As a portion only of the atmospheric air, probably not much more than a fourth or a fifth part, is renewed at each ordinary respiratory movement when the body is in a state of rest, the air expelled during expiration will chiefly consist of that occupying the larynx, trachea, and the larger bronchial tubes; so in the same manner, the air drawn in by inspiration will chiefly occupy the same parts of the respiratory apparatus. It is well known that the air expelled in the first part of an expiration contains less carbonic acid than that expelled towards its close; thus the air in the deeper parts of the respiratory apparatus must be richer in carbonic acid and poorer in oxygen than that in the upper parts. The amount of intermixture of the gases in the different parts of the respiratory apparatus effected by the muscular movements of the chest would, in all probability, be too imperfect for the proper arterialisation of the blood, were this not aided by the well-known tendency of gases to diffuse themselves through each other. As the air in the air-cells differs from that in the higher parts of the respiratory apparatus in containing more carbonic acid and less oxygen, the nitrogen being nearly the same in both, this diffusion of gases is probably chiefly confined to the two former. From the oxygen being of lighter specific gravity than the carbonic acid gas, the descending current of oxygen gas will exceed the ascending current of carbonic acid, and 81 parts of carbonic acid will be replaced by 95 of oxygen, for according to the law regulating the diffusion-volumes of gases under such circumstances, established by Graham, in the case of each gas this is inversely proportional to the square root of its density.*

*On the nature of the actions between the blood and the atmospheric air in the lungs, by which a quantity of oxygen is removed from the inspired air, and a quantity of carbonic acid gas added to the expired air.*—Four views have been maintained on this point.—1. That of Lavoisier, La Place, and others; that the oxygen which disappears from the inspired air unites directly in the lungs with hydrocarbon furnished by the venous blood, and forms the carbonic acid gas and watery vapour that escape along with the expired air.†

2. That of La Grange and Hassenfratz; that free carbonic acid gas is present in a state of solution in the venous blood before it arrives at the lungs, where this gas is exhaled; that nearly the whole of the oxygen gas abstracted from the inspired air is absorbed at the lungs, and held in solution by the arterial blood; and that the combination of the oxygen with the carbon and formation of carbonic acid chiefly take place when the blood is passing through the capillaries of the systemic circulation.*

3. That the oxygen that disappears from the inspired air enters into chemical combination with one or more of the constituent parts of the blood in its course through the lungs, that in the passage of the blood through the capillaries of the systemic circulation this oxygen leaves the substance or substances to which it had united itself, and combines with carbon to form carbonic acid, or with carbon and hydrogen to form carbonic acid and water, and that the carbonic acid thus formed does not combine chemically with any of the constituent parts of the venous blood, but is held in solution by it, and is evolved while passing through the capillaries of the lungs.

4. That not only the oxygen that disappears from the inspired air is united chemically in the arterial blood, but also the carbonic acid formed during its circulation through the systemic capillaries enters into chemical combination with some one of the constituent parts of the venous blood; that the combination thus formed is decomposed in the pulmonic capillaries by the agency of the absorbed oxygen, and the carbonic acid thus set free is evolved and escapes in the expired air.

The first view, viz. that the carbonic acid that appears in the expired air is formed in the lungs by the combination of part of the oxygen of the inspired air with the carbon of the venous blood, must now be regarded as untenable. The existence of free gases in the blood, the evolution of carbonic acid from the blood at the lungs in animals made to breathe gases devoid of oxygen, the small increase of

* Edinburgh Transactions of Royal Society, vol. xii. p. 573. 1834.

† Seguin and Lavoisier "Sur la Transpiration des Animaux," in Mémoires de l'Académie des Sciences for 1790, p. 601. It is still maintained by some chemists and physiologists, who appear to regard the function of respiration simply as a process of combustion, but who do not uphold the opinion that this combustion takes place in the lungs and that the watery vapour in the expired air is immediately derived from this source, that a part of the oxygen that disappears from the inspired air unites with hydrogen to form water. No satisfactory evidence is offered in support of this opinion, and in the present state of our knowledge it must be regarded as a mere conjecture.

* This doctrine, as propounded by Hassenfratz (Annales de Chimie, tom. ix. p. 261. 1791), which has received various modifications since his time, was based on the view that the purple colour of the venous blood is the result of the combination of oxygen with the carbon and hydrogen of the blood, while the scarlet colour of arterial blood is caused by the solution of oxygen gas in it, and consequently there can be little combination of the carbon and hydrogen of the blood with the atmospheric air in the lungs.

temperature the blood acquires in its change from the venous to the arterial condition*, and the result of observations made upon the blood out of the body, when subjected to alternate applications of oxygen and carbonic acid gas, are all opposed to the supposition that the formation of carbonic acid gas takes place to any great extent in the lungs. The existence of a quantity of free carbonic acid in the venous blood, more than sufficient to furnish the whole of this gas thrown off at the lungs, and the avowedly conjectural explanation of the manner in which the carbonic acid is combined and the agency by which its combinations are decomposed in the lungs, given by those who advocate this view, justify the adoption of the opinion that the carbonic acid gas evolved at the lungs exists in a free state in the venous blood before it reaches the lungs.

An interchange, therefore, takes place between the air in the cells of the lungs and the blood in the pulmonic capillaries, the latter receiving oxygen and giving up part of the free carbonic acid held by it in solution. These gases, from their solubility, readily permeate the thin moist membranes interposed between the blood and the atmospheric air contained in the cells of the lungs. We have already mentioned that Valentin and Brunner have concluded from their experiments that this interchange of oxygen and carbonic acid gas is regulated by the law of the diffusion of gases established by Graham; but besides the objections that may be urged against this view, drawn from the considerable diversity in the relative proportions of these gases interchanged during respiration as ascertained by different experimenters, the conditions under which the two gases are placed in respiration are very different from those in the experiments instituted by Graham.† In respiration the gases are separated by moist animal membranes, and one of these, viz. the carbonic acid, is held in solution in a fluid subjected to an increased pressure caused by the action of the heart.*

We are not, in the present state of our knowledge, in a condition to form any thing like an accurate estimate of the various circumstances which regulate this interchange between the oxygen of the air and the carbonic acid gas of the blood, but it is obvious that it will be affected in a most important manner by the relative proportion of these gases in the air contained in the air-cells of the lungs and in the blood, and by the quantities of atmospheric air and blood transmitted through the respiratory apparatus.

We have seen, from the experiments of Vierordt, that when the air is rapidly renewed in the lungs, though the percentage of carbonic acid in the expired air is diminished, yet the total amount of this gas thrown off from the lungs within a given time is proportionally increased; while, on the other hand, when the respirations are diminished below the natural standard, though the percentage of carbonic acid in the expired air is increased, yet the total quantity thrown off from the lungs in a given time is proportionally diminished. When the atmospheric air in the lungs is rapidly renewed by an increased frequency of the respiratory movement, the diffusion of the oxygen in the higher, and of the carbonic acid in the deeper, parts of the air tubes will proceed more rapidly, and the air in the deeper parts or in the air-cells will contain a less percentage of carbonic acid, and a greater percentage of oxygen, than when the respirations are carried on with the usual frequency and force. This diminution of the usual quantity of carbonic acid gas and increase of oxygen in the deeper parts of the lungs will accelerate the interchange between the oxygen of the air and the carbonic acid of the blood, provided the blood holds its normal amount of free gases in solution, and a larger quantity than usual of carbonic acid will be separated from the blood at

* Dr. J. Davy ascertained (Lond. Philos. Trans. for 1838, p. 298) that oxygen gas shaken with venous blood out of the body raised the temperature of the latter from 1° to 2° Fahr. Marchand (Journal für praktische Chemie, Band xxxv. S. 400) adduces reasons for believing that this increase in temperature arose from the mere absorption of the gas, and not from any chemical action between it and the blood.

† Graham's first experiments, from which he deduced his law that "the diffusive velocities of different gases are inversely as the square root of their densities," were made by interposing a porous septum of stucco between the gases experimented upon and the external air. The equivalent diffusion-volumes of oxygen and carbonic acid calculated according to this theory, with which the experimental results closely agree, are—air being equal to 1, oxygen 0·9487, and carbonic acid 0·8091. (Transactions of Royal Society of Edinburgh, vol. xii. p. 222. 1834.) In some later experiments Mr. Graham ascertained that this law also held when gases pass through minute apertures in a thin plate into a vacuum, while, on the other hand, the discharge of the same gases through tubes into a vacuum has no uniform relation to the density of the gases. (Philosophical Transactions of London for 1846, p. 573.)

* The passage of gases through moist membranes is not simple diffusion, as it is influenced by the solubility of these gases in the fluids of the membranes. In the case of respiration it will also probably be affected by the attractive force of the constituents of the blood for the gases. The relative rapidity of the passage of different gases through membranous septa, as observed in the experiments of Dr. Faust and of Mr. Mitchell (American Journal of the Medical Sciences, Nov. 1830), and by other experimenters, is not in accordance with the law of the diffusion of gases, as determined from experiments upon their diffusive velocities through porous septa into the atmospheric air, and through minute apertures in a thin plate into a vacuum. When a bladder filled with oxygen gas is introduced into a vessel full of carbonic acid gas, the latter passes so much more rapidly through the coats of the bladder than the former, that the bladder becomes gradually distended, and at last may burst. In these last experiments, equally as in those of Graham, the conditions under which the diffusion of the gases occurs, are not the same as those in respiration; and we find the carbonic acid gas passing in greater quantity through the organic membranes than the oxygen,—the reverse of what takes place in respiration.

the lungs, and carried out in the expired air. If, then, we add an increased flow of blood through the capillaries of the lungs to an increased frequency of the respiratory movements, as occurs in exercise, the interchange between the oxygen of the air and the free carbonic acid of the blood will be carried on with greater activity. When, on the other hand, the air is renewed in the lungs less frequently than usual, as happens when the respiratory movements are diminished in number and in extent, the air in the deeper parts of the lungs will contain less oxygen and more carbonic acid than usual, and the interchange between the oxygen of the atmospheric air and the free carbonic acid of the blood will proceed more slowly. When the respirations are reduced to about one half of their normal frequency, as occurs in the course of some diseases, and after division of the vagi nerves, the carbonic acid gas gradually accumulates in the blood, less oxygen is absorbed, and the individual generally sooner or later dies of asphyxia. When the quantity of carbonic acid gas in the air-cells reaches a certain amount, the evolution of this gas from the blood will cease; and when this is carried still farther, there will be an absorption of a part of the carbonic acid gas by the blood.

The interchange between the nitrogen and the other gases at the lungs is very small in the normal condition of the respiration, but there is every reason to believe that this is regulated by circumstances similar to those which determine the interchange of the oxygen and carbonic acid. The nitrogen is much less soluble in the blood than the oxygen and carbonic acid, and we presume that its power of permeating moist animal membranes is much inferior to these gases, and that the smaller quantity of it held in solution in the blood may be in this manner explained. We have already pointed out that, in the experiments made to determine whether nitrogen is absorbed or exhaled at the lungs, opposite results have been obtained, but that the evidence preponderates in favour of the opinion that a small quantity of this gas is evolved from the blood during respiration. By an alteration of the usual relation between the quantities of nitrogen present in the air and in a free state in the blood, the evolution of nitrogen from the blood may be increased or suspended, or it may be absorbed by the blood instead of being evolved by it. In a previous part of this article we have referred to experiments which prove that when animals breathe oxygen or hydrogen gases, or a mixture of both, azote is evolved in greater quantity than usual from the blood in the lungs; and that when they breathe azote alone, part of this gas is absorbed at the lungs.

The exact condition in which the whole of the oxygen absorbed at the lungs exists in the blood, notwithstanding the light thrown upon this point by recent researches, is still not free from considerable difficulties. Previous to the experiments of Magnus upon the gases of the blood, already referred to, the opinion of Le Grange and Hassenfratz, that the greater part of the oxygen gas absorbed at the lungs is dissolved in the blood and carried along with it in that condition to the systemic capillaries, was considered untenable by many celebrated physiologists, the more especially as the attempts to detect free oxygen in the arterial blood had failed in all the more trust-worthy experiments. Different opinions as to the kind of chemical combination formed by the oxygen in the arterial blood have been entertained by those who believe that the portion of this gas that disappears from the inspired air does not unite with carbon in the lungs to form carbonic acid, and that little or none of it is simply dissolved in the arterial blood. In the greater number of these hypotheses, however, the oxygen is supposed to unite itself in whole or in part to the red corpuscles, and especially to the iron contained in these: and as the exact state in which the metal exists in the red corpuscles is still undetermined, this has given rise to very different notions regarding the changes effected upon it by the oxygen. According to other views, the oxygen in whole or in part is united chemically to some of the other constituent parts of the arterial blood, and from these it is again separated in passing through the systemic capillaries, and unites with carbon to form carbonic acid.*

* We shall here very shortly notice a few of the more recent theories of respiration, which proceed on the supposition that the oxygen abstracted from the inspired air is combined, in whole or in part, with some of the constituents of the arterial blood. Gmelin, Tiedemann, and Mitscherlich (Zeitschrift für Physiologie, Band v.) supposed that the oxygen absorbed at the lungs partly unites with carbon and hydrogen to form carbonic acid and water which are there exhaled, and partly with organic substances in the blood to form acetic and lactic acids: that these acids decompose some of the carbonates of soda brought to the lungs in the venous blood, and that the carbonic acid thus set free is also exhaled. The arterial blood in its course through the tissues, more especially those of the kidneys and skin, loses part of its acetic and lactic acids; and the soda with which they were combined, being set free, unites with the carbonic acid formed during the process of nutrition, and these carbonates are again decomposed in the lungs in the manner described. Dumas (Statique Chimique des Etres Organisés, pp. 43, 44, 3me édit.) believes that the absorbed oxygen combines with certain matters of the blood and forms lactic acid, the lactic acid combines with soda to form lactate of soda, and this latter salt, by a real combustion, is converted into carbonate of soda, which is decomposed in its turn in the lungs by a fresh portion of lactic acid. Liebig (Organic Chemistry of Physiology and Pathology, edited by Gregory, p. 265. 1841) supposes that carbonate of protoxide of iron exists in the red corpuscles of venous blood, and that in its passage through the lungs, a large portion of the absorbed oxygen unites with it, forms hydrated peroxide of iron, and sets the carbonic acid free. Mulder (The Chemistry of Vegetable and Animal Physiology, translated by Fromberg, Part II. p. 337) affirms that an alternate change into carbonate of the protoxide of iron and peroxide of iron in respiration is impossible, and maintains that the absorbed oxygen combines with the proteine compounds of the blood and forms oxy-proteine, which being conveyed by the

The presence of a larger quantity of free oxygen gas in the arterial blood than what is sufficient to form the carbonic acid gas evolved at the lungs, amounting in some cases to rather more than 10 per cent. of the volume of the blood in the experiments of Magnus, naturally leads to the conclusion that the greater part, at least, of the absorbed oxygen is not chemically combined in the arterial blood, and is simply held in solution by it. We are not, however, quite prepared to concur in the opinion of Magnus, that the *whole* of the absorbed oxygen is held in solution in the arterial blood, and that an interchange between part of the free carbonic acid of the venous blood, and part of the oxygen of the atmospheric air, embraces the entire changes in the blood as it passes from the venous to the arterial condition: for, if the opinion be correct that the elaboration of the materials of the chyle into blood is completed in the lungs, and that certain marked differences in the fibrin of the two kinds of blood, noticed above, really exist, something more than this is probably necessary. Though the experiments of Marchand appear to prove that the absorbed oxygen does not enter into any chemical combination with the constituent parts of the arterial blood in the lungs, by which carbonic acid gas is formed; yet, while the greater part of the absorbed gas is held in solution in the arterial blood, a small portion of it may enter into chemical combination in a manner hitherto not definitely ascertained.*

It is almost universally believed that the free carbonic acid gas in the blood is formed by the combination of the absorbed oxygen with carbon in the blood, chiefly if not entirely in the course of its circulation through the systemic capillaries; but this opinion, however plausible it may appear, and though it apparently accounts for the evolution of animal caloric in a satisfactory manner, does not rest upon any direct evidence. There are no facts that militate against the existence of such a combination, and there can be no doubt that in the present state of our knowledge it affords the readiest and most complete interpretation of the phenomena referred to it, but still it is quite possible that the carbonic acid may be formed during the process of nutrition differently from what is generally supposed.

*Cause of the change of colour in the blood.* — The manner in which the changes of colour in the blood is effected as it passes through the pulmonic and systemic capillary vessels, has not yet been satisfactorily determined. It seems now to be pretty generally admitted that the hæmatosine or colouring matter of the blood is enclosed within the enveloping membrane of the red corpuscles; that this hæmatosine, though it may be combined with iron, does not derive its colour from the presence of this metal; and that all attempts to explain the change in the colour of the blood in the lungs by the formation of certain oxides and salts of iron must be abandoned. It is well known that various substances, besides oxygen gas, can impart a bright red colour to venous blood when mixed with it, and without being attended with any evolution of carbonic acid gas. The best known of these are solutions of the sulphate of soda, nitrate of potass, phosphate of soda, carbonate of soda, carbonate of potass, and sugar.

The opinion of Stevens *, that the change from the venous to the arterial hue in the blood is to be attributed to the actions of the salts dissolved in the blood upon the hæmatosine, after the removal of the free carbonic acid of the venous blood through the attractive force of the oxygen of the atmospheric air, has not been confirmed by subsequent researches. It has been ascertained that the removal of carbonic acid from venous blood, by means of the air-pump †, or by agitation

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arterial blood to the capillaries is decomposed during the nutritive processes, and carbonic acid is formed and held in solution in the blood.

[Dr. G. O. Rees has lately put forward the following ingenious theory of respiration. He finds by analysis that the corpuscles of venous blood contain fatty matter in combination with phosphorus, which does not exist in arterial blood, or, at most, is found in it only in very small quantity. In respiration the oxygen of the inspired air unites with this phosphorus and fatty matter, and a combustion of it takes place, of which the products are water and carbonic acid, from the union of the oxygen with the elements of the fatty matter, and phosphoric acid, from the union of the oxygen with the phosphorus. The carbonic acid and water are exhaled, and appear in the expired air; the phosphoric acid attracts the soda of the liquor sanguinis from its combination with albumen and lactic acid, and thus forms a tribasic phosphate of soda, a salt which possesses in a marked degree the property of giving a bright colour to hæmatosine. See Dr. Rees' paper in the Lond. Edin. and Dubl. Phil. Mag. for July, 1848. — Ed.]

* Marchand (Journal für praktische Chemie, Band xxxv. S. 385. 1845) in his experiments found that oxygen gas does not unite with fibrin to form carbonic acid until it has been exposed to its action for some days, in fact not until it is passing into a state of putrefaction; and that, on subjecting to a continuous current of oxygen gas, the red corpuscles, and beaten venous blood, after all the free carbonic acid held in solution had been carefully separated by the air-pump and agitation with hydrogen, no carbonic acid gas was evolved. These experiments invalidate the inferences in favour of the opinion, that the oxygen absorbed at the lungs partly enters into combination with the constituents of the blood in the lungs and forms or liberates carbonic acid gas, drawn from the experiments of Scherer (Annalen der Chemie und Pharmacie, Band xl. 1841) upon the action of oxygen gas upon fibrin, and those of Berzelius (Lehrbuch der Chemie, Band iv. S. 94. 1831), and Maack (De Ratione quæ Colorem Sanguinis inter, &c., p. 35. Kiliæ 1834) upon the greater absorbing power for oxygen of the colouring matter of the blood over the serum. Mulder (Holländische Beiträge, &c. Band i. heft i. B. 20. 1846) adduces various arguments to show that the experiments of Magnus, and they apply equally to those of Marchand, by no means prove that a part of the oxygen absorbed at the lungs does not enter into chemical combination with the constituents of the blood before it reaches the capillaries of the systemic circulation.

* London Philos. Transact. vol. xlvi. p. 345. 1835.

† Dr. J. Davy and others.

with hydrogen gas * and the addition of a saline solution, of the same strength as that existing in the blood †, will not impart to it the arterial hue, if oxygen gas be not at the same time present. The oxygen gas, therefore, acts directly, and not indirectly by removing the carbonic acid, in changing the colour of the blood; but as a small quantity only of this gas is sufficient, when the salts are present in their usual quantity, to produce this effect ‡, the action of the oxygen, in changing the colour of the blood in respiration, will be aided by the presence of the salts.

In the present state of our knowledge, there is some difficulty in deciding whether the reddening of the blood by the absorbed oxygen be entirely a physical action, or whether it be partly physical and partly chemical, seeing that several accurate observers, who have recently investigated this point, have arrived at very different conclusions.

The opinion, first promulgated by Dr. Wells §, that the change from the venous to the arterial hue arises from an increased reflection of light in the red particles, caused by the presence of the absorbed oxygen, and without any chemical change upon the hæmatosine, has of late obtained several supporters. Those who have adopted this view do not, however, agree in their explanation of the manner in which this increased reflection of light is effected; some maintaining that it arises from an alteration in the form of the red corpuscles, and that this change consists in the biconvex corpuscles of the venous blood, becoming biconcave in the arterial blood ‖; while others believe that the action of the oxygen on the blood is analogous to that of the nitrous oxide on the solutions of the salts of iron, changing their colour without entering into chemical union with them.*

We may, in the meantime, conclude that the change in the blood from the venous to the arterial hue in the lungs, is a physical and not a chemical action; and that though there is pretty strong evidence in favour of the opinion that this physical change consists in an alteration of the form of the red corpuscles, yet it is not free from doubt.

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* Bischoff, Dr. Maitland, Nasse, and Marchand.

† Gregory and Irving (vide London Medical Gazette, vol. xiii. p. 814. 1834). Nasse (Wagner's Handwörterbuch, &c., Band i. S. 182) affirms that even concentrated solutions of muriate of soda, nitrate of potassa, and carbonate of potass, cannot impart the true arterial hue to venous blood, without the presence of a small quantity of oxygen; and that when Stevens saw the blood redden under the air-pump, there must have been sufficient oxygen still present in the rarefied air to act on it with the aid of the salts.

‡ Nasse (opus cit. p. 182). He also infers from his experiments that oxygen can redden the blood without the presence of salts (p. 187).

§ London Philos. Transact. for 1797, p. 416.

‖ Scherer, Reuter, and Gulliver. Mulder (The Chemistry of Animal and Vegetable Physiology, p. 341, 342.) also contends that the arterial hue depends upon the red particles assuming the biconcave form and reflecting more light, but he gives a very different explanation of the cause of the change in the form of the red particles from the other supporters of this view. According to Mulder, part of the oxygen absorbed unites with some of the proteine compounds in the blood in the lungs, and forms oxyproteine, and this furnishes a thin envelope to the red corpuscles, and by its contraction causes them to assume the biconcave form. This opinion is supported neither by direct observation nor by experiment. Marchand (Journal für praktische Chemie, Band xxxviii. § 276, 277) and Dumas (Comptes Rendus for 1846, tom. xxii. p. 900) after separating the red corpuscles from the other constituents of the blood, and washing them in a solution of sulphate of soda, found that they still changed from the venous to the arterial colour on the addition of oxygen. Dumas concludes, that neither the presence of albumen nor fibrin is necessary to enable oxygen to redden venous blood; and Marchand, after a careful experimental investigation, affirms that the supposition that the changes of colour in the blood are from a chemical action, is attended with insuperable difficulties (opus cit. Band xxxviii. S. 278).

* Magnus and Marchand.

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